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Low Emission Energy Scenarios for the European Union

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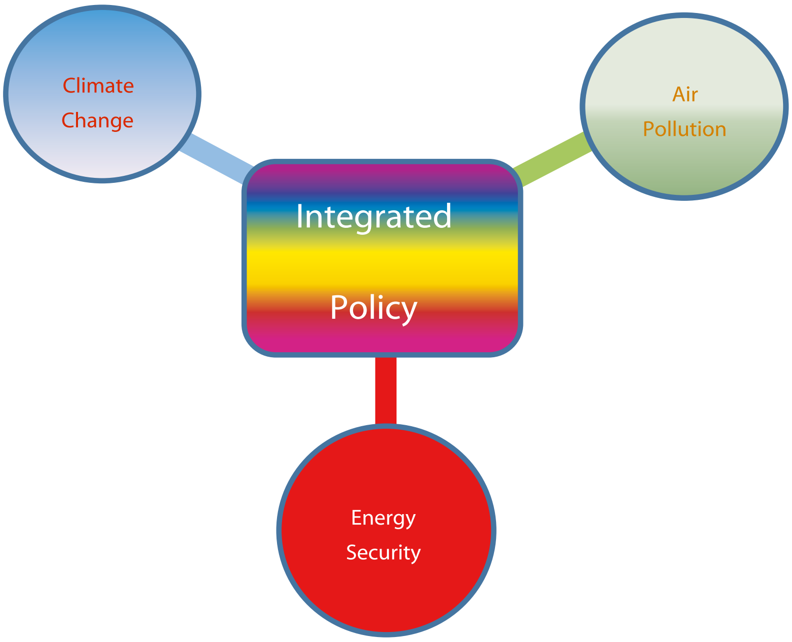

Low Emission Energy Scenarios for the European Union

Author:
Mark Barrett
Complex Environment Systems Group
Bartlett School of Graduate Studies
University College London

NATURVÅRDSVERKET

Beställningar
Ordertel: 08-505 933 40
Orderfax: 08-505 933 99
E-post: natur@cm.se
Postadress: CM-Gruppen, Box 110 93, 161 11 Bromma
Internet: www.naturvardsverket.se/bokhandeln

Naturvårdsverket
Tel: 08-698 10 00, fax: 08-20 29 25
E-post: natur@naturvardsverket.se
Postadress: Naturvårdsverket, SE-106 48 Stockholm
Internet: www.naturvardsverket.se

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Preface

This work reported here was carried out by Mark Barrett in response to a request by Anna Engleryd, the Swedish Environmental Protection Agency for information to aid the Working Group on the revision of National Emissions Ceilings and Policy Instruments (NECPI). The focus of this work is the technical and economic assessment of common policy measures that simultaneously aid the achievement of emissions ceilings for air pollutants, control carbon dioxide emissions from fossil fuels, a principal greenhouse gas, and improve energy security by reducing energy demand with efficiency and increasing renewable energy.

The author have the sole responsibility for the content of the report and as such it can not be taken as the view of the Swedish Environmental Protection Agency.

Stockholm in December 2007

Naturvårdsverket

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Comments and suggestions from Simone Schucht of the Institut National de l'Environnement Industriel et des Risques (INERIS) greatly improved both the analysis and the text.

Errors are the responsibility of the author.

Mark Barrett, University College London.
51 Gordon Square, London WC1H 0PQ, UK.
Mark.Barrett@ucl.ac.uk

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Executive Summary

Energy consumption is a major cause of carbon dioxide emission, and also largely determines the uncontrolled emissions of many other pollutants. In consequence, energy scenarios are key inputs to the projection of pollution emission, and the formulation of strategies to reduce pollution and achieve environmental objectives. Alternative energy strategies including behavioral change, demand management, energy efficiency, and low carbon fuels are explored in this report. In addition to abating greenhouse gas emissions, these strategies can facilitate cheaper and greater abatement of other atmospheric pollutants as compared to higher carbon scenarios. In general, achieving a given air pollution emission target costs less in a low carbon scenario than in a high carbon scenario. This work is aimed at producing policies that exploit the positive synergy between strategies to limit global warming, and strategies for reaching other environmental objectives such as reduced acidification and improved air quality. Low carbon energy scenarios can improve energy security by reducing the consumption if finite fuels and reducing import requirements.

The given objective was to produce scenarios in which the total emission of carbon dioxide from the twenty-five countries of the European Union is reduced by at least 30% over the period 1990 to 2020. To this end scenarios have been produced for each of the twenty-five EU countries taking into account recent historical data and assumed economic and population growths taken from other studies, and selections of policies measures.

The scenarios show that, as compared to 1990, CO_2 reductions of more than 30% are feasible by 2020, and that larger reductions are possible, especially in the longer term as technologies with long lifetimes such as power stations, are replaced. Data from the energy scenarios were input to the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model of IIASA (International Institute for Applied Systems Analysis), and the reductions in air pollution and the costs of air pollution control were there calculated.

Apart from emission control, the policy options lead to a reduction in the import of finite fossil and fissile fuels into the EU and so they enhance supply security in a world with increasing competition for these dwindling resources.
The policies required to implement the technical changes to demand and energy systems assumed have not been explored here.

Svensk sammanfattning

Produktion och konsumtion av energi är viktiga källor till utsläpp av koldioxid och andra luftföroreningar. Därför är energiscenarier viktiga vid upprättandet av strategier för att minska luftföroreningars miljöpåverkan.

I denna rapport behandlas alternativa energistrategier för EU 25 som inkluderar livsstilsförändringar, efterfrågestyrning, energieffektivisering och användandet av bränslen med låg kolhalt.

Jämfört med att enbart titta på varje förorening eller växthusgas för sig kan samordnade strategier leda till större utsläppsminskningar till en lägre kostnad.

Syftet med denna rapport är att visa på de positiva synergier som finns mellan begränsningar av växthuseffekten och strategier för att uppnå andra miljömål såsom minskad försurning och förbättrad luftkvalitet.

Alternativa energiscenarier som ger minskningar av koldioxidutsläppen på mer än 30 % över EU fram till år 2020 jämfört med 1990, har tagits fram och effekterna på andra luftföroreningar och kostnader studerats med hjälp av den så kallade GAINS modellen.

1. Background

The development of strategies in the European Union for the control of greenhouse gases, acidification, ozone and a range of air pollutants, use energy scenarios extensively. Energy consumption is a major cause of the emission of greenhouse gases (GHG), most notably carbon dioxide (CO_2), and to a range of atmospheric pollutants that damage human health and ecosystems. Therefore energy scenarios are key inputs to the projection of pollution emission and to the formulation of strategies to reduce pollution and achieve environmental objectives.

At the outset of this study in the autumn of 2006, a 30% reduction in EU25 CO_2 over the period 1990 to 2020 seemed very ambitious as compared to political intent. However, in March 2007, European Union leaders agreed targets of 20% and 30% reductions in greenhouse gas emissions and energy targets such that renewable energy should meet 20% of energy consumption by 2020. (Appendix 3 gives some analysis of the renewable fraction.)

The particular focus here is on energy scenarios used in the development of National Emission Ceilings (NECs) in the Working Group on the revision of National Emissions Ceilings and Policy Instruments (NECPI). The terms of reference for NECPI are set out here:
http://ec.europa.eu/environment/air/cafe/general/meetings_workshopstocome.htm
The energy scenarios developed here contribute to integrated assessment modelling and cost-benefit analysis; in particular to address this term of reference for the NECPI Working Group: "(a) The improvement of modelling parameters, databases and scenarios such as the Maximum Technical Feasible Reduction Scenario."

Currently, energy scenarios generated using the PRIMES model by the National Technical University of Athens (NTUA) are one of the main sets of scenarios used in NECPI. Certain outputs from these scenarios are input to the GAINS model of IIASA which is used to calculate environmental impacts and find the optimal, least cost selection of options to meet NECs and other targets. However, the energy options in GAINS are incremental changes from a base energy scenario input from another model, such as PRIMES, or source, such as a Member State.

Energy scenarios largely determine the uncontrolled emissions of controlled primary air pollutants including sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM) and secondary pollutants including ozone and PM, prior to the application of 'End-Of-Pipe' (EOP) abatement technologies such as flue gas desulphurisation and catalytic converters.

An overarching objective of environment and energy policy can be assumed to be the improvement of social conditions and the economy. With respect to energy and the environment, improved energy security and reduced global warming and air pollution will reach towards this objective. In order to improve energy systems and reduce concomitant pollution, physical changes to the energy system need to be made. The energy system includes people and the network of energy technologies and sources they use to meet their needs. Ultimately, all changes to social energy systems are brought about by human behaviour whether as private individuals or in collective enterprises; whether it's the demand for energy services, or the choice and use of energy technologies. To change the energy system to meet the overall objective therefore requires changes in human behaviour, but in this report behaviour is taken to be consumer 'lifestyle' behaviour such as choice of car.

These physical changes will be called measures and they may be categorised into behavioural, demand management, efficiency, renewables and End-Of-Pipe (EOP). These are summarised in the Table below. Options 1-4 are called Non End of Pipe (NEOP) options: this is a clumsy term and is used because sometimes various of the options 1-4 are called Non Technical Measures (NTMs) which can be confusing if it is an option such as gas CHP (Combined Heat and Power).

Also, the term NTM is often used to refer to options such as road pricing, that do not directly specify technical or technological change – it is proposed that these be called instruments rather than NTMs.

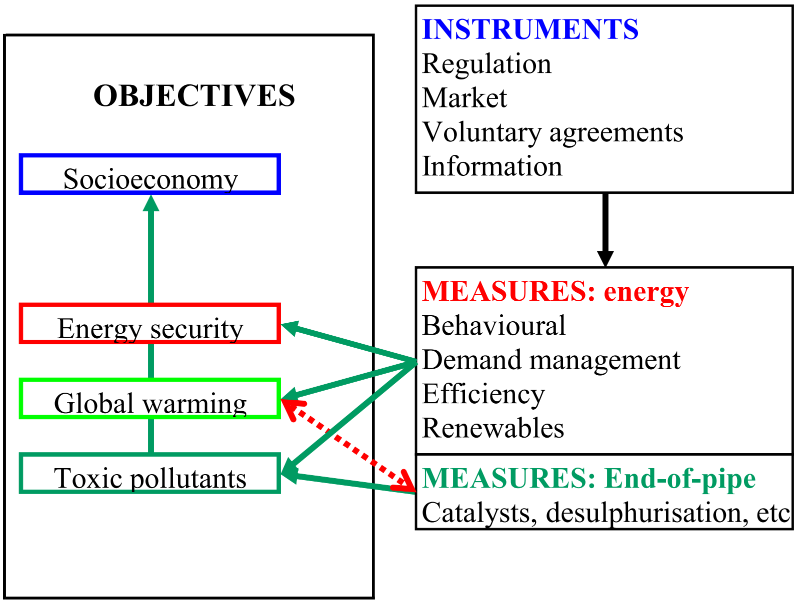
Table 1 Emission control measure categories

		Category	Examples
1	NEOP	Behavioural change	Smaller cars, lower speeds
2	NEOP	Demand management	Building insulation, low energy appliances, transport demand
3	NEOP	Improved energy conversion efficiency	Condensing boilers, CHP, Combined Cycle Gas Turbines
4	NEOP	Fuel switching to lower carbon	From coal and oil to gas, renewables and nuclear
5	EOP	End-of-pipe	Flue gas desulphurisation, catalytic converters, and carbon sequestration

Note: NEOP-Non End Of Pipe; EOP- End Of Pipe

In order to change behaviour, instruments may be deployed. These may be categorised as regulation (e.g. emission standards), market (e.g. emission taxes), voluntary agreements (e.g. CO_2 emissions of vehicles, and information (e.g. appliance efficiency labelling). There is no discussion in this report of the instruments that might be deployed to implement the physical measures. The next Figure illustrates how instruments effect measures in order to meet policy objectives.

Figure 1: Objectives, measures and instruments



Important to an integrated policy are options such as more demand management, energy efficiency and use of low impact fuels as compared to the 'official' scenarios. Historically, the emphasis has been on EOP options for the control of non-GHGs. This is partly because large reductions in some pollutants, such as SO_2, could be achieved at low cost with EOP technologies implemented through regulation such as the Large Combustion Plant Directive, without requiring large changes to the energy economy; and because, in general, global warming and greenhouse gases have not been regulated by EU legislation historically. However, as tighter limits have pushed up the costs of EOP options, and concern about global warming has increased, and some political commitment to controlling it has followed within individual Member States and the EU as a whole, there has been a greater emphasis on developing integrated policies that address the multiple environment problems of global warming and air pollution. This is particularly because measures to control greenhouse gases generally also reduce air pollutants, and thereby stringent targets for both can be achieved at a lower total cost than addressing each separately.

'End-of-pipe' abatement technologies generally decrease energy efficiency and some produce wastes, and decreasing energy efficiency usually increases carbon dioxide emissions. For example: flue gas desulphurisation may decrease the efficiency of electricity generation by 5% and require limestone inputs and produce waste gypsum; carbon sequestration by pumping CO_2 into depleted reservoirs can decrease energy efficiency by 10-35% and hence increase primary CO_2 production.

Furthermore, in addition to abating greenhouse gas emissions, NEOP options generally decrease the emissions of air pollutants such as SO_2 and NO_x because fossil fuel combustion is reduced. NEOP options facilitate greater emission abatement than is possible with EOP measures alone, and the total combined cost of meeting greenhouse gases and air pollutant targets is generally less than in scenarios which do not include the extensive use of NEOP.

NEOP solutions, with the exception of switching between fossil fuels, also reduce dependence on fossil fuels and improve security of supply. Natural gas and oil are especial cause for concern because the remaining world reserve lives are measured in decades. The use of gas, particularly for electricity generation, has been an important option for reducing both acid and CO_2 emissions. Now, the depletion of European gas and oil fields gives concern about energy supply security because of the need to import, and causes pressure to increase the use of indigenous fuels with environmental disadvantages, such as coal.

1.1. This study

The basic remit of this study is to produce energy scenarios for the twenty-five European Union countries such that the total carbon dioxide emissions from fossil fuel combustion are reduced by 30% or more by 2020 as compared to 1990. These scenarios assume extra CO_2 abatement measures being introduced in 2008, and would therefore have ten years at most to take effect to achieve a reduction in 2020. Judgements as to which measures to introduce have been based on technical feasibility, cost effectiveness and speed of introduction.

One specific aim here is to develop energy scenarios with the SEEScen (Society Energy and Environment Scenario) model that has a detailed implementation of NEOP measures such as insulation in buildings or the selection of cars with lower power. The scenarios are input to the GAINS model and the air pollution emissions and EOP costs assessed; this analysis is in chapter 7. Apart from the defined environmental objectives pursued in the scenarios, there are other objectives such as energy security which are important, but these are not generally addressed explicitly or in detail.

The energy flows in these scenarios are put into the same categories as in IIASA's GAINS model which may then be used to generate EOP costs. The GAINS model may then be used to find optimal allocation of EOP measures to achieve given reduced levels of acid deposition and ground-level ozone, but this is not part of the work in this report.

The work is in two basic parts: first, develop one energy scenario for each EU25 country in which CO_2 emissions are significantly controlled for the period 2005 to 2020 such that total EU CO_2 emission is reduced by at least 30% by 2020 as compared to 1990; second, adjust and convert the scenario energy data to be consistent with data inputs to IIASA's GAINS model. This work is accomplished in the following steps:

I. Update databases.
II. Set targets for CO_2 in 2020.
III. Set constraints on NEOP measures. Particularly important are assumptions about nuclear power.
IV. Construct scenarios so as to meet energy goals such as minimising net energy trade into the EU, so as not to effectively ’export’ energy and environment problems, and to improve energy security. The scenarios utilise a mix of NEOP measures such that goals are met for each EU25 country. A model called SEEScen (Society, Energy and Environment Scenario) will be used. The scenarios assume that extra CO_2 abatement measures were introduced in 2008, and it is from this date that the scenarios would diverge.
V. Output the scenario energy flows and costs for each country, and for the EU25 as a whole.
VI. Transfer energy data into a form suitable for IIASA's GAINS model, and run the GAINS model.

The scenarios cover the EU25. Countries and international standard 2 and 3 letter codes are given in the next Table.

Table 2 EU25 country codes

Entity	ISO 2	ISO 3		Entity	ISO 2	ISO 3
Austria	AT	AUT		Latvia	LV	LVA
Belgium	BE	BEL		Lithuania	LT	LTU
Cyprus	CY	CYP		Luxembourg	LU	LUX
Czech Republic	CZ	CZE		Malta	MT	MLT
Denmark	DK	DNK		Netherlands	NL	NLD
Estonia	EE	EST		Poland	PL	POL
Finland	FI	FIN		Portugal	PT	PRT
France	FR	FRA		Slovakia	SK	SVK
Germany	DE	DEU		Slovenia	SI	SVN
Greece	GR	GRC		Spain	ES	ESP
Hungary	HU	HUN		Sweden	SE	SWE
Ireland	IE	IRL		United Kingdom	GB	GBR
Italy	IT	ITA				

1.2. Scope of emissions

The energy model SEEScen projects the demands and energy consumption for all activities in society, including international aviation and shipping. Currently the energy use and emissions from international aviation and shipping — so called bunker fuels — are excluded from the Kyoto Protocol.

“In accordance with the IPCC [Intergovernmental Panel on Climatic Change] *Guidelines for the preparation of greenhouse gas (GHG) inventories and the UNFCCC* [United Nations Framework Convention on Climate Change] *reporting*

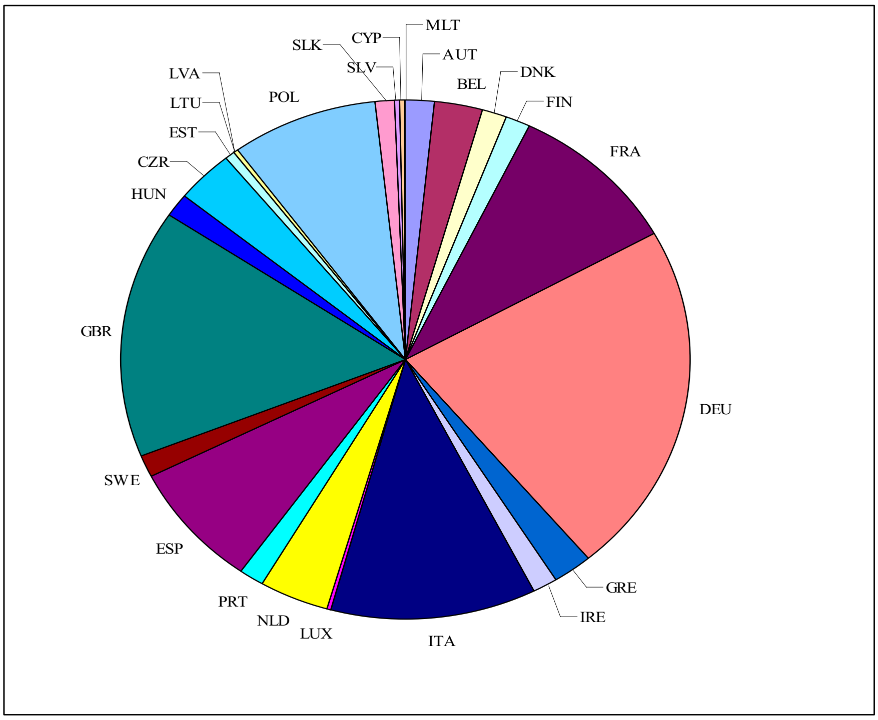
guidelines on annual inventories, emissions from international aviation and maritime transport (also known as international bunker fuel emissions) should be calculated as part of the national GHG inventories of Parties, but should be excluded from national totals and reported separately. These emissions are not subject to the limitation and reduction commitments of Annex I Parties under the Convention and the Kyoto Protocol."
http://unfccc.int/methods_and_science/emissions_from_intl_transport/items/1057.php

1.3. EU carbon dioxide emission targets

This section summarises EU25 CO_2 emissions and the setting of emission targets for 2010 and beyond. Fossil fuel CO_2 emissions data are taken from the Carbon Dioxide Information Analysis Centre (CDIAC) for data published in 2005 (CDIAC, 2005).

The Figure below shows the distribution of fossil fuel CO_2 emissions in 2000 across the EU25. The 'Big Six' (Germany, UK, Italy, France, Poland and Spain) accounted for about 75% of EU25 emissions, with Germany and the UK accounting for about 40% of emissions.

Figure 2 EU25 Fossil fuel CO2 emissions in 2000



Source: CDIAC (2005)

Most of the individual countries of the European Union, and the EU25 as a whole, have committed to reductions in the emissions of a basket of greenhouse gases in the Kyoto protocol. The commitments are to changes in emission from a 1990 base to be achieved by 2008-2012.

Under the Protocol, the EU15 (the 15 countries that were Members of the EU at the time of ratification of the Protocol) is committed to reducing its greenhouse gases emissions by 8% below 1990 levels during the first commitment period from 2008 to 2012. This target is shared between the 15 Member States under a legally binding burden-sharing agreement, which sets an individual emissions target for each Member State. Of the ten Member States that acceded on 1 May 2004, eight have individual reduction targets of 6% or 8% under the Kyoto Protocol. Only Cyprus and Malta do not have Kyoto targets.

The next Table summarises the commitments.

Table 3 EU greenhouse gas emission burden sharing

Region	Target	Emissions in 2003	2008-2012 with existing policies & measures (PAMs)	2008-2012 with additional PAMs and/or Kyoto mechanisms
EU15	8.00%	-1.70%	-1.60%	-9.30%
EU25	-	-8.00%	-5.00%	-11.30%
Austria	13.0%	16.6%	8.7%	-18.1%
Belgium	-7.5%	0.6%	3.1%	-7.9%
Denmark	21.0%	6.3%	4.2%	na
Finland	0.0%	21.5%	13.2%	0.0%
France	0.0%	-1.9%	9.0%	-1.7%
Germany	21.0%	-18.5%	-19.8%	-21.0%
Greece	25.0%	23.2%	34.7%	24.9%
Ireland	13.0%	25.2%	33.4%	na
Italy	-6.5%	11.6%	13.9%	-3.7%
Luxembourg	28.0%	-11.5%	-22.4%	na
Netherlands	-6.0%	0.8%	3.5%	-8.5%
Portugal	27.0%	36.7%	52.1%	42.2%
Spain	15.0%	40.6%	48.3%	21.0%
Sweden	4.0%	-2.4%	-1.0%	-
United Kingdom	12.5%	-13.3%	-20.3%	-
Czech Republic	-8.0%	-24.3%	-25.3%	-26.5%
Estonia	-8.0%	-50.8%	-56.6%	-60.0%
Hungary	-6.0%	-31.9%	-6.0%	-
Latvia	-8.0%	-58.5%	-46.1%	-48.6%
Lithuania	-8.0%	-66.2%	-50.6%	-
Poland	-6.0%	-32.1%	-12.1%	-
Slovakia	-8.0%	-28.2%	-19.7%	-21.3%
Slovenia	-8.0%	-1.9%	4.9%	0.3%
Cyprus				
Malta				

Source: Europa, 2006

The indications are that the EU25, in aggregate, will meet its 2010 Kyoto commitment, but only with additional measures and Kyoto mechanisms.

In 2003, the most recent year for which data is available, the EU15 had reduced its emissions by 1.7%. EU-wide emissions were down by 8%. Projections show that additional policies and measures planned by the Member States but not yet implemented and use of the Kyoto flexible mechanisms will take EU15 emissions to 9.3% below 1990 levels by 2010 - more than enough to meet the 8% reduction target - while EU25 reductions will reach 11.3%. Only six Member States were not on track to meet their targets: Denmark, Ireland, Italy, Portugal, Slovenia and Spain (see annex for details).

1.3.1. Post 2010 targets

This study is investigating emission control for years later than 2010, with a particular focus on 2020. The question then is what the overall EU25 targets for GHG should be, and how these are allocated to individual countries.
First, we define the scope of GHG covered in terms of gases and sectors, and the geographical inclusion.

- GHG included. Only CO_2 from fossil fuel burning is included in the targets, and it is assumed that this CO_2 emission has to meet the same percentage targets as the basket of GHGs. CO_2 arising from other combustion (e.g. forestry), or processes (e.g. cement manufacture), and other gases such as methane, are not included in the targets developed below.
- Measures in non-EU countries. In this study, it is assumed that targets are met using emission control with measures within EU25 countries only; GHG control achieved by measures outside the EU25, through mechanisms such as FlexMex or CDM is not included.

Then we need to make assumptions about targets beyond Kyoto, for 2020 in particular. The Presidency Conclusions of the Council of The European Union (CEU, 2005) stated:
The European Council emphasises the EU's determination to reinvigorate the international negotiations by:
– exploring options for a post-2012 arrangement in the context of the UN climate change process, ensuring the widest possible cooperation by all countries and their participation in an effective and appropriate international response;
- developing a medium and long-term EU strategy to combat climate change, consistent with meeting the 2ºC objective. In view of the global emission reductions required, global joint efforts are needed in the coming decades, in line with the common but differentiated responsibilities and respective capabilities, including significantly enhanced aggregate reduction efforts by all economically more advanced countries. Without prejudging new approaches for differentiation between parties in a future fair and flexible framework, the EU looks forward to exploring with other parties strategies for achieving necessary emission reductions and be-

lieves that, in this context, reduction pathways for the group of developed countries in the order of 15-30% by 2020, compared to the baseline envisaged in the Kyoto Protocol, and beyond, in the spirit of the conclusions of the Environment Council, should be considered. These reduction ranges will have to be viewed in the light of future work on how the objective can be achieved, including the cost-benefit aspect. Consideration should also be given to ways of effectively involving major energy-consuming countries, including those among the emerging and developing countries;
– promoting cost-efficient measures to cut emissions.

Targets for reduction in total EU25 1990 fossil CO_2 by the year 2020 are set. The question then is how the required reductions for the whole EU25 might be allocated to individual Member States.

It was originally intended to develop scenarios such that EU25 and individual country targets were met, with burden sharing through country targets devised with principles of equity. However, the differing demands and energy resources of countries, and the time required to detail policies country by country, has meant this has not been possible in this work to propose burden sharing of either the CO_2 or renewable energy supply targets.

It is anticipated that quantifying burden sharing will require lengthy and complex analysis and negotiation. Therefore, the CO_2 reductions and renewable energy component of each country has been set in the scenarios by judgements about the further economic potential of energy efficiency and energy sources based on data available to the study.

Elements of the intended approach to burden sharing are set out in Appendix 1.

1.3.2. Energy trade and carbon emission

The aim is to achieve environmental and other objectives at least cost. Ideally, this would mean optimising energy strategy across all demand and supply options and all countries of the world. It makes economic sense to import renewable energy resources into a country if they can be obtained at lower cost and so, in a globally optimised strategy, trade in energy would occur. The economic advantage of trade is tempered by considerations of energy security.
The existing databases and models are not adequate for a global optimisation of both demand and supply, particularly when there is a large renewable component of supply. SEEScen works country by country and does not endogenously account for trade between countries. However, the net trade for each country is calculated and this may be summed across the EU to find trade for the whole region, although this give no indication of trade between pairs of EU countries. Trade and energy security is discussed in section 6.3.1.

Furthermore, in the particular scenarios explored here, exogenous assumptions concerning nuclear generation are made, some following those in the PRIMES scenarios. The assumptions about nuclear generation are often partially based on current political intents in each country, rather than on technology appraisal. The assumed nuclear generation represents a significant fraction of the EU25 renewable electricity generation potential. Countries with assumed new nuclear generation and significant renewable electricity sources become exporters of electricity in the SEEScen scenarios.

How is traded energy accounted for in carbon? For the fossil fuels, the carbon emissions of fossil fuels consumed within that country (apart from international transport fuels) are calculated simply and accurately using coefficients of carbon per GJ/tonne/therm. Fossil fuel exports do not appear in the carbon balance of the exporting country because carbon emissions from these appear in the importing, consuming countries.

The carbon content of generating electricity depends on how the electricity is generated and this often varies from hour to hour. Emissions from generation within a country appear in the national carbon balance. Unlike fossil fuels, the carbon content of electricity at the point of consumption is zero. The question is how to account for electricity trade and emissions. The simplest option is to assign zero carbon to traded electricity because the exporting country will be benefiting economically, earning money from those exports, and the importing country will be disbenefitted in trade balance, though benefiting overall by purchasing energy more cheaply than it can generate it. However, this approach has limitations when considering the net carbon emissions of a region and emission targets.

This issue is unresolved in this report, but is discussed in section 6.3.1 with reference to particular scenarios; in the base scenario studied here, the EU25 has net exports of electricity and net imports of fossil gas and oil.

1.4. The scenarios

Six scenarios were modelled: a central scenario with a 30% reduction in EU25 CO_2 emission by 2030, and five variant scenarios with various combinations of NEOP measures and different assumptions about nuclear power. The scenarios are generally labelled Region: Percentage reduction fossil CO_2 from 1990: reduction date: Nuclear (new nuclear as in PRIMES)/ No Nuclear (no new nuclear). The scenario of central focus is labelled **EU30pc20N**, meaning Europe Union: 30% reduction from 1990 by 2020; nuclear generation as assumed in PRIMES.

The second scenario (**EU40pc20N**)sets a 40% CO_2 reduction target with new nuclear stations, and the third (EU30pc20NN a 30% CO_2 reduction target with no new nuclear stations The last three scenarios look at the effect of applying technological and behavioural options to the maximum separately and both together.

Table 4 Scenarios

Label	Target: % CO_2 reduction from 1990	Target: Reduction date	Nuclear energy	NEOPs
EU30pc20N	30	2020	New	Mix
EU40pc20N	40	2020	New	Mix
EU30pc20NN	30	2020	No new	Mix
TecNN			No new	Maximum technology
BehNN			No new	Maximum behavioural
TecBehNN			No new	Maximum technology and behaviour

A number of points should be emphasised :

- The starting point of a scenario is the last year of historical data which usually take 2 or more years to verify and make available; for example, the International Energy Agency (IEA) energy data for 2004 were available in the summer of 2006. Thus scenarios do not start from the present and when analysing near term targets for 2010 or 2020 the error can be large. New historical data arrive each year, and so the starting point of the scenarios developed here is different from other scenarios more than a year old.
- All historical databases almost certainly contain numerical and categorical errors.
- There are no fixed rates of change for measures. Coal fired power stations might be decommissioned after 40 years, or after 20.
- There are large uncertainties in all predictions of economic and social development, and technological innovation.

For these reasons, the scenarios will not be accurate in absolute terms. What is important, therefore, are the measures that the scenarios indicate that might be beneficent in environmental, economic and other terms.

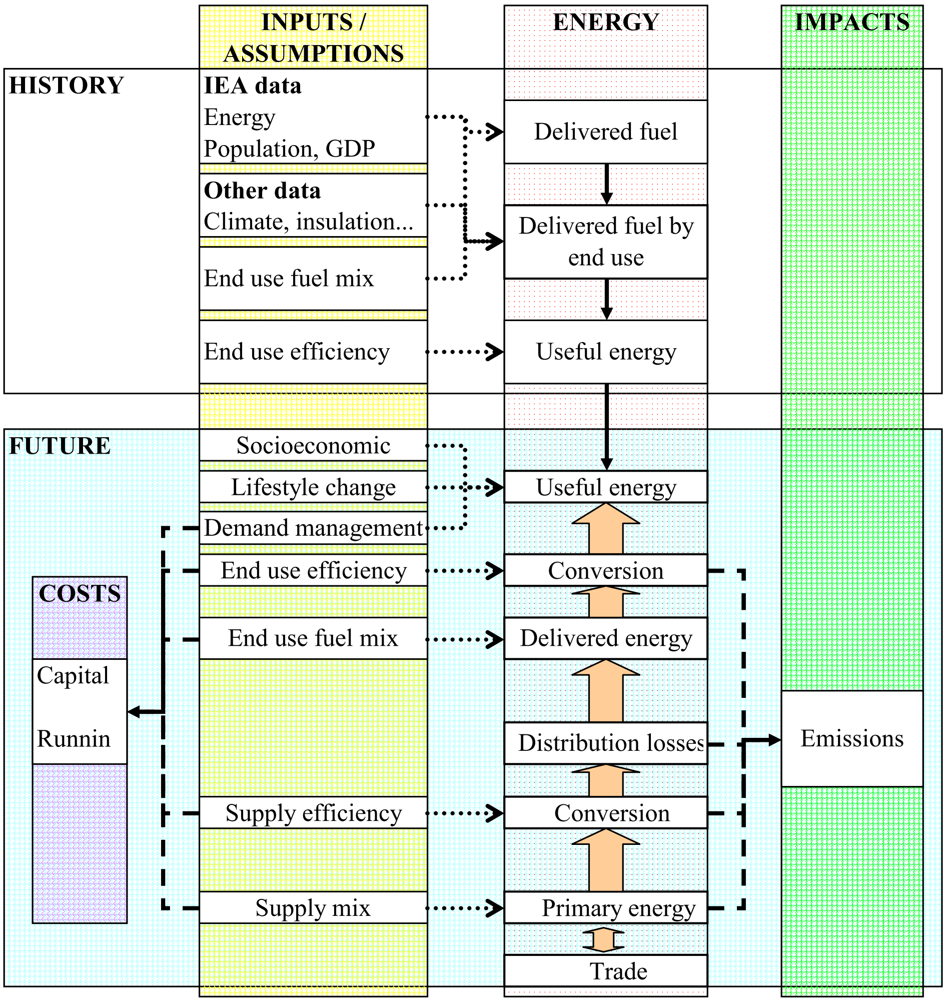
2. Modelling the Scenarios

2.1. SEEScen model

The scenario model is called SEEScen (Society Energy and Environment Scenario). It is designed to produce energy scenarios which may be used in the analysis of environmental impacts. It is a simulation model: assumptions about policy options are input the model and it calculates the outcomes in terms of energy, costs and emissions. It does have a single year optimisation mode, but that is not used here, partly because of the conceptual problem of assigning costs to behavioural change.

The structure of the model is shown schematically in the next Figure.

Figure 3 SEEScen model overview



The IEA has assembled a database of the energy statistics for most countries of the world (IEA, 2006), the most recent data year available for this study being 2004. These data have been compiled into country energy balances. These balances include sectoral data for the consumption and production of fossil fuels, hydro, nuclear, geothermal and other renewables, electricity and heat. This database also includes GDP and population.

The consumptions of delivered fuel in 2004 are allocated to eleven end uses as shown in the next Table– they are ordered by temperature. Some of these end uses are generally regarded as electricity specific; others can utilise heat from cogeneration or other sources such as solar energy (as opposed to fossil fuels or electricity). These features are also shown in the Table uses marked 'e' can practically only use electricity.

Table 5 End uses and supply restriction

End use	**Electricity specific**
Motive power	e
Electrical equipment	e
Process work	
Lighting	e
Process heat (>120C)	
Process heat (<120 C)	
Cooking	
Water heating	
Space heating	
Space cooling	e
Refrigeration	e

Delivered fuels by end use are multiplied by a set of efficiencies to produce useful energy consumed for the eleven end uses such that the delivered fuels calculated match historically recorded. This establishes useful energy consumption for the last year for which there are IEA data (2004).

These useful energy data are then projected into the future using 'energy activity functions' based on estimates of future population, households and GDP data from other sources. These estimates may be endogenous, or as in this case, exogenous, taken from the PRIMES scenarios. Every scenario for a particular country assumes the same demographic and economic changes - i.e. these are invariant. In these scenarios, further exogenous data are used for transport demand and nuclear generation.

The basic projection of useful energy is then modified according to control measures changes in behaviour (Be) such as car downsizing, and demand management (DM) such as insulation.

Useful energy demands are allocated to an end use supply mix. For example; water heating might be allocated to a mix of energy converters including solar heating, electric heat pumps and CHP district heating.

Energy deliveries to the end user are calculated by dividing the useful energy by the appropriate projected efficiencies of end use converters.

After adding on distribution losses, and allowing for imports and exports the requirements for domestic inland energy supply may be found.

Supply side efficiency improvements and fuel switching are then applied so that the fuel used in energy supply industries may be calculated.

If the potential electricity production from non fossil sources is greater than domestic demand, the surplus is exported. This electricity could be used to replace carbon based generation in another country. SEEScen accounts for exports.

Emissions and costs are calculated for each component of the energy system.

2.2. Comments on the SEEScen model

The SEEScen modelling system has been developed for specific purposes. Like all models it has strengths and weaknesses.

Strengths include:

- It is a ‘bottom’ up model with physical descriptions of demand, demand management and technologies.
- It can be used to rapidly identify the technical potential of different policy options.
- It can be used to generate scenarios for any country for which there are IEA data, which is all major countries of the world. Since the IEA data are published annually, the model always has a recent fuel use database to base projections on. Furthermore, the IEA collate a number of other statistical series which are useful inputs to the modelling process.
- The model can be used to rapidly explore the effects of different programmes in energy strategies for many countries in any geographical or political grouping. The profile of programmes, in terms of change in fuel use and the time and rates of change can be easily altered. The programmes can be applied in any combination and thus the effect of each can be isolated and analysed separately.
- The output of SEEScen can be automatically converted into the files and formats required by IIASA’s GAINS model.

Principal weaknesses include:

- When exogenous assumptions are not used, SEEScen growth projections are based on population and GDP using simple functions which do not include detailed market processes such as saturation.

- It does not incorporate the responses of economic agents to costs and prices with elasticities.
- It does not include consideration of how technical changes to the energy system might be brought about by instruments such as taxation or regulation.

SEEScen does calculate the emissions of air pollutants, though the emission factors require development. The model can be used to arrive at the total additional cost of reaching a set of environmental objectives encompassing targets for the emissions of energy related greenhouse gas and air pollutant emission.

3. Exogenous Assumptions Used in the Scenarios

3.1. Background

The system of people, ecosystems, energy and the environment is one global interconnected system, but it is not presently possible to model it all in any useful detail. Accordingly, in all modelling exercises, there are data input to the model – exogenous data or assumption – and data calculated endogenously through the relationships between variables in the model. The starting point for these energy scenarios is to compile assumptions about the basic drivers of energy consumption – population, households, GDP, and sectoral economic activity. Other exogenous assumptions include international energy prices and particular policies affecting sectors such as buildings, transport and electricity generation, but these are not explicitly included here.

Such assumptions are exogenous to many energy models. In reality, energy and environment scenario outcomes will affect some or all of these exogenous assumptions: for example, lower CO_2 emission generally results from lower fossil fuel consumption which causes fossil fuel prices to be lower than in a higher consumption scenario; and energy prices affect activities, GDP and household formation, if only marginally.

Some exogenous inputs, such as transport demand are dependent on a range of policies. For example, the distance travelled by people each year depends on a complex of factors such as land use patterns, road provision, city traffic cordons, and transport pricing. The distance travelled may be influenced by policies in order to meet aims such as reduced congestion, economic savings, and a safer, less polluted local environment; as well as less CO_2 emission. (For example: the London congestion charge does all these things.) In other words, these measures may be called NEOP measures for the control of distance travelled and thereby CO_2 emission.

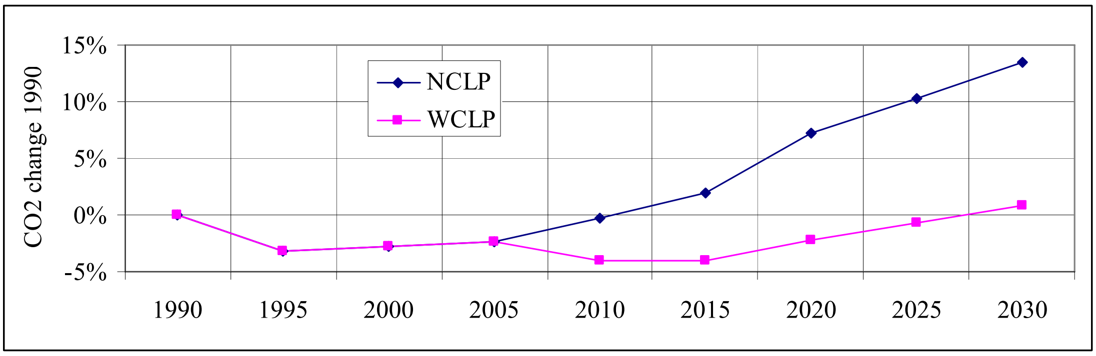
The aim here is to use certain assumptions about drivers and other key measures made in the PRIMES scenarios, but make different assumptions about NEOP measures so as to reduce CO_2 emission to lower levels than in the PRIMES scenarios. There is a difficulty here in that some measures are explicitly included in SEEScen, but are not, as far as is known, in PRIMES; for example, SEEScen has a explicit data concerning the size and insulation levels for dwellings, and a model of dwellings as they operate in the specific climate of a country. (This is not to imply that SEEScen is superior to PRIMES, just that it handles some parts of the energy system differently.)

The basic future socioeconomic context and energy scenarios for Europe are described in several documents, with these being useful general descriptions. These were chosen from those publicly available and documented in mid 2006 (other scenarios have been produced since then); they are as follows:

- European Commission Directorate-General for Energy and Transport, September 2004, European Energy and Transport Scenarios on Key Drivers. (DGTren, 2004) http://europa.eu.int/comm/dgs/energy_transport/figures/scenarios/doc/summary.pdf
- DGTren (European Commission Directorate-General for Energy and Transport), January 2003, European Energy and Transport Trends to 2030. (DGTren, 2003) http://www.eu.int/comm/dgs/energy_transport/figures/trends_2030/1_pref_en.pdf
- Using these scenarios as background, the PRIMES model was used to develop detailed scenarios, as described in Long-Term Scenarios For Strategic Energy Policy of the EU (NTUA, 2005). This may be downloaded from: http://ec.europa.eu/environment/air/cafe/general/keydocs.htm
- For this work, two PRIMES scenarios are used: No Climate Policies (NCLP); and With Climate Policies (WCLP). For each EU25 country, data for two scenarios are given and may be downloaded from this web site: www.europa.eu.int/comm/dgs/energy_transport/figures/trends_2030/index_en.htm

PRIMES calculates CO_2 emission from fossil fuel use. The next Figure shows the index of total CO_2 emission in two scenarios. It is to be noted that neither scenario meets the EU25 target for 2010 (excluding FlexMex) and that both show increasing emission after 2015. It may be that the inclusion of non-CO_2 gases, the 2010 targets are met.

Figure 4 EU25 CO_2 emission change in the NCLP/WCLP PRIMES scenarios



Note: No Climate Policies (NCLP); With Climate Policies (WCLP)

It is to be noted that if the total fossil fuel energy is higher than required by GHG targets, the cost of reducing NEC emissions to a certain level will probably be higher; moreover, the possibilities of reduction will probably be less, thus lowering economically achievable emission targets.

These PRIMES scenarios extend out to 2030. Any data presented here for years after that date are simple extrapolations. In general, key exogenous assumptions input to the NCLP and WCLP scenarios are identical, or have small differences as summarised in the next Table.

Table 6 Exogenous assumptions — variation by scenario

	Item	**NCLP/WCLP variation**
Socioeconomic	Population	None
	Households	None
	GDP	None
Transport	Passenger	Slight
	Freight	Slight
Fuel prices	Oil, coal, gas	None
Nuclear generation		Small

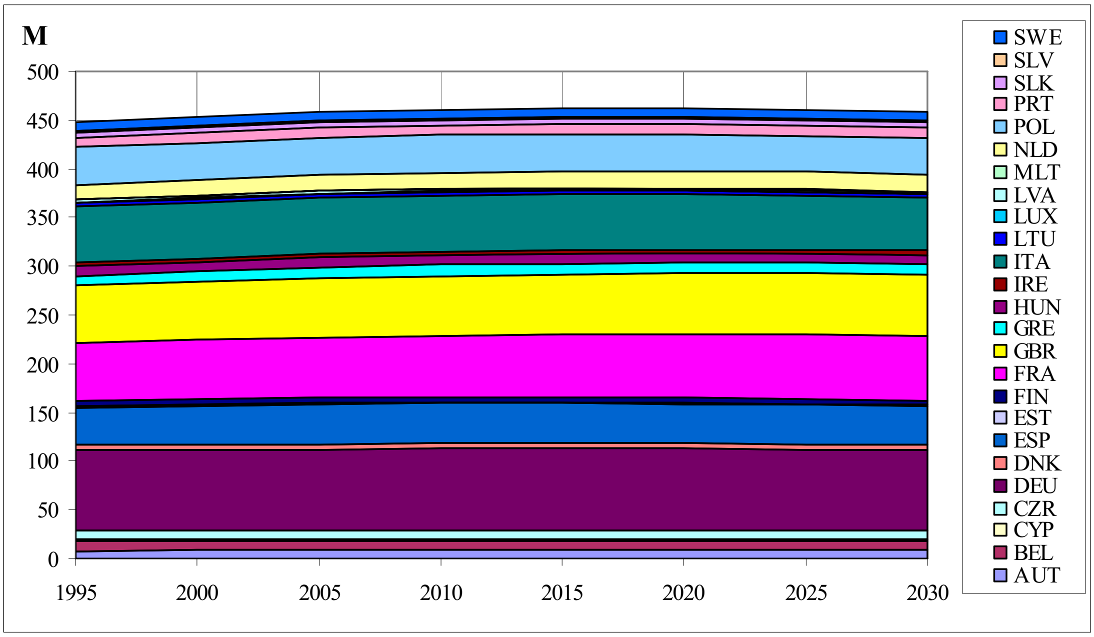
3.2. Energy and climate policy dependent assumptions

The following sections briefly describe the assumptions which are adopted from the PRIMES scenarios.

3.3. Demography

The EU25 population is forecast to grow slowly to a peak in 2015, after which it gradually declines.

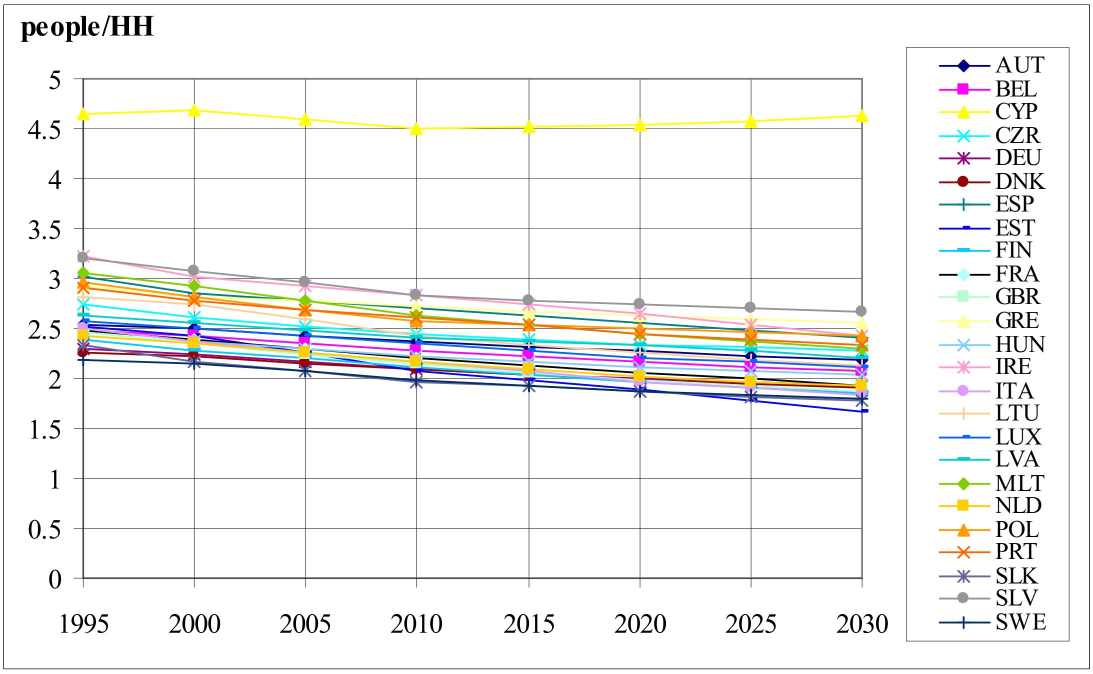
Figure 5 Population in millions (M)



Source: PRIMES NCLP scenario

Increasing wealth and other social changes result in smaller households.

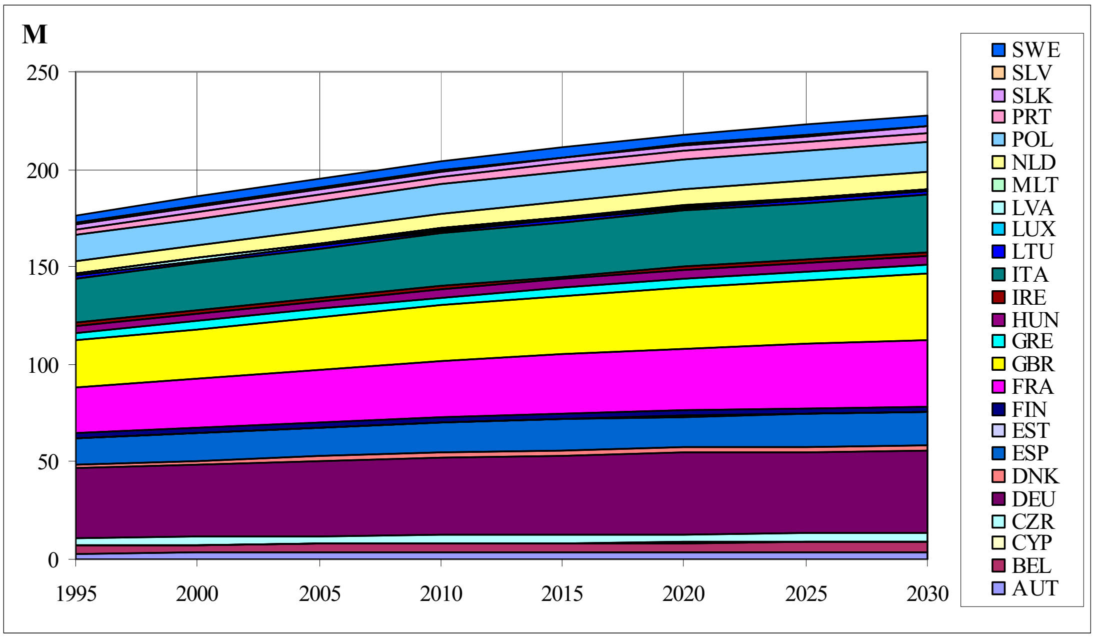
Figure 6 People per household



Source: PRIMES NCLP scenario

Due mainly to the decline in household size, there is an increase in the number of households. The number of households is an important determinant of energy consumption because energy use per person generally increases with decreasing household size: this is because building floor and envelop area per person increases, and the ownership and use of many energy using technologies (e.g. cars, refrigerators) is strongly related to the number of households as well as the number of people.

Figure 7 Households



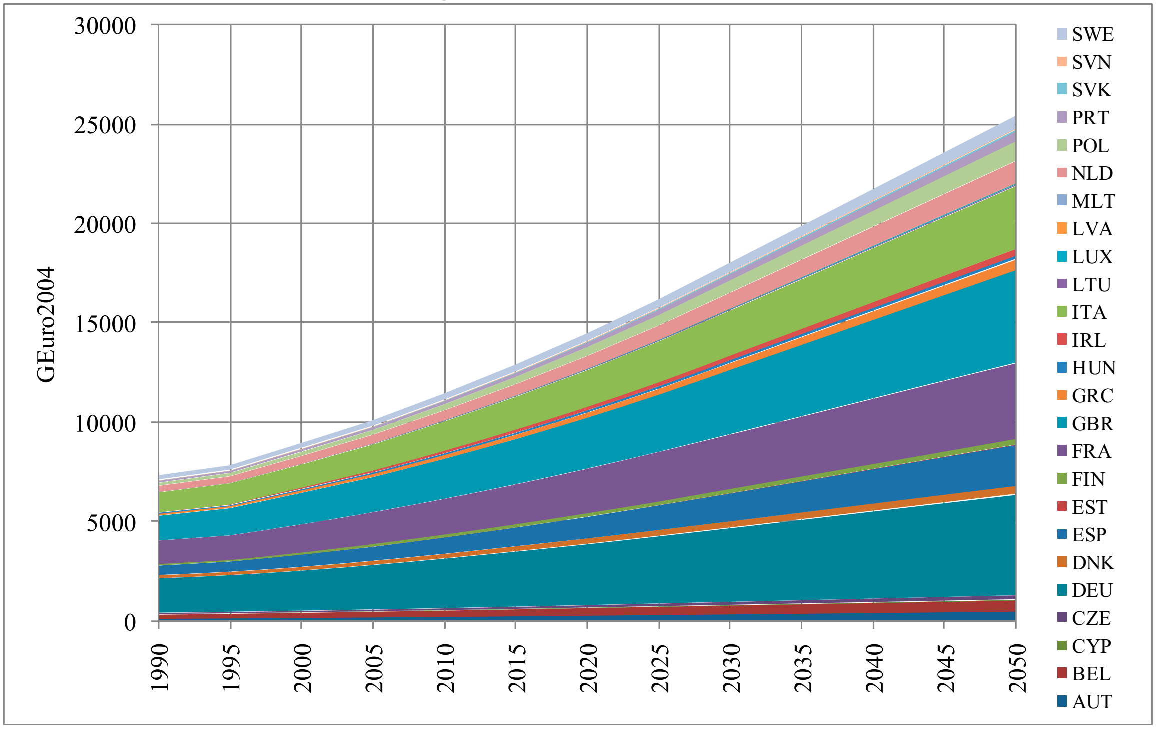
Source: PRIMES NCLP scenario

3.4. Economy

Wealth is an important driver of energy consumption. Once levels of wealth are sufficient that basic needs such as adequate thermal comfort are met, wealth may be spent on inessential or leisure needs some of which, such as air travel, more powerful cars, or larger houses, increase energy consumption and associated emissions. Conversely, there can be decoupling of wealth and energy and emissions for some commodities and services because of saturation. For example; once living temperatures rise to a comfortable maximum, increasing wealth will not result in higher temperatures and associated energy and emissions. The surplus wealth ‘saved’ by this saturation might be spent on something with a lower emission per Euro, such as jewellery, or something with a higher emission, such as air travel.

A steady growth in GDP is forecast in the PRIMES scenario. GDP growth is higher in the services sector than the industrial sector. The next Figure shows GDP in billion of Euros (2004).

Figure 8 GDP



Source: PRIMES NCLP scenario

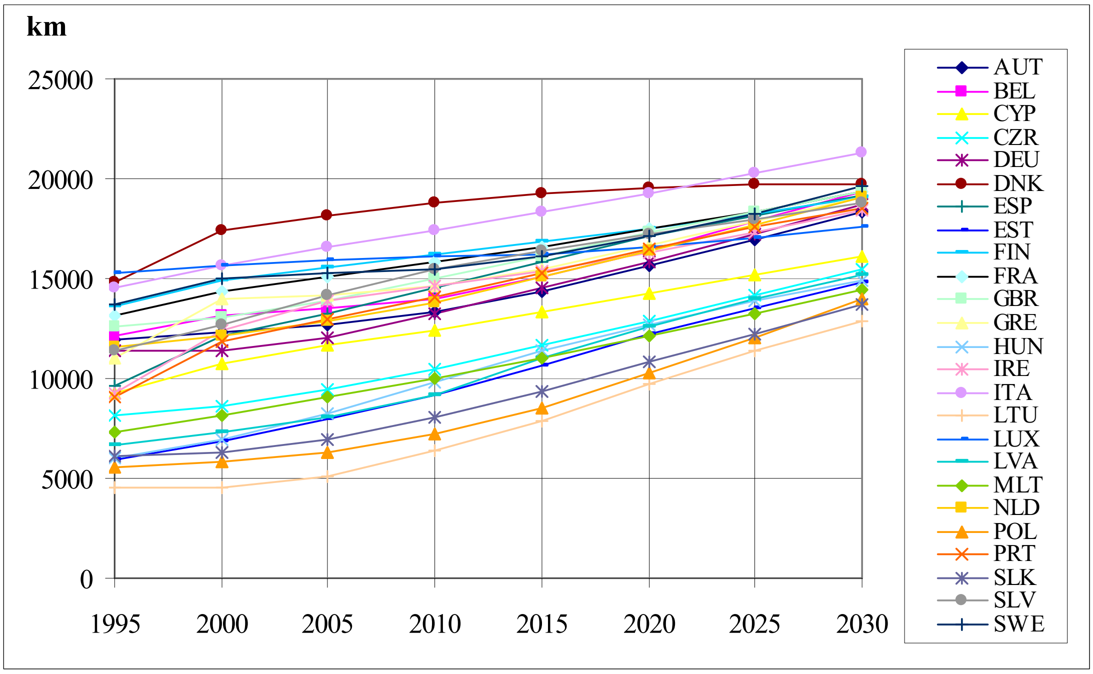
3.5. Demand

Of fundamental importance to energy scenarios are the demands for energy. These arise in two ways: first, from direct consumer demand for energy-based services, such as space heating or transport; and second, through the energy required by industry and services sectors to provide these services and commodities.

3.5.1. Transport

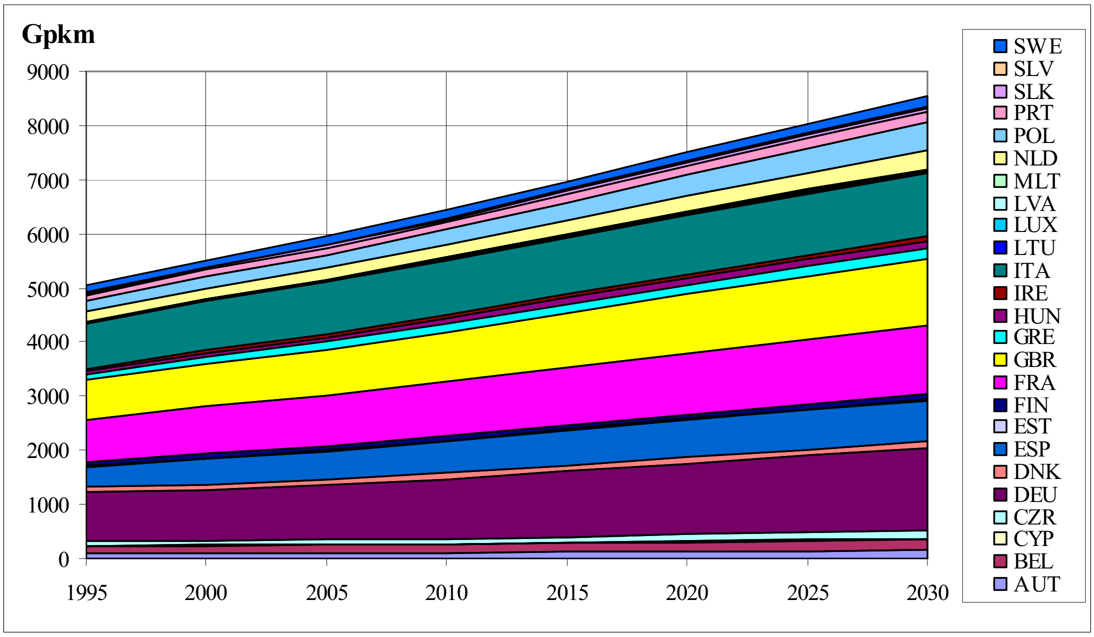
The PRIMES NCLP scenario assumes a steady increase in distance travelled per person and thence an increase in total distance for the population of about 44% over the period 2005 to 2030.

Figure 9 Passenger transport per capita



Source: PRIMES NCLP scenario

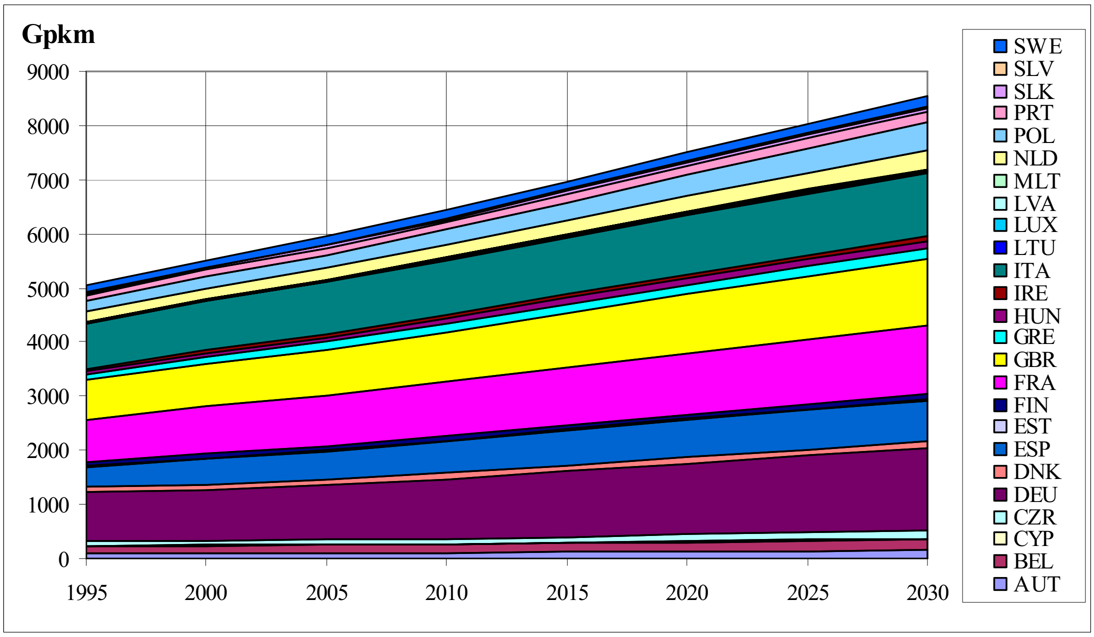
Figure 10 Passenger transport (billion p.km)



Source: PRIMES NCLP scenario

The EU25 average is that about 75% of passenger km are by car across the PRIMES scenario years, but this fraction varies between countries.

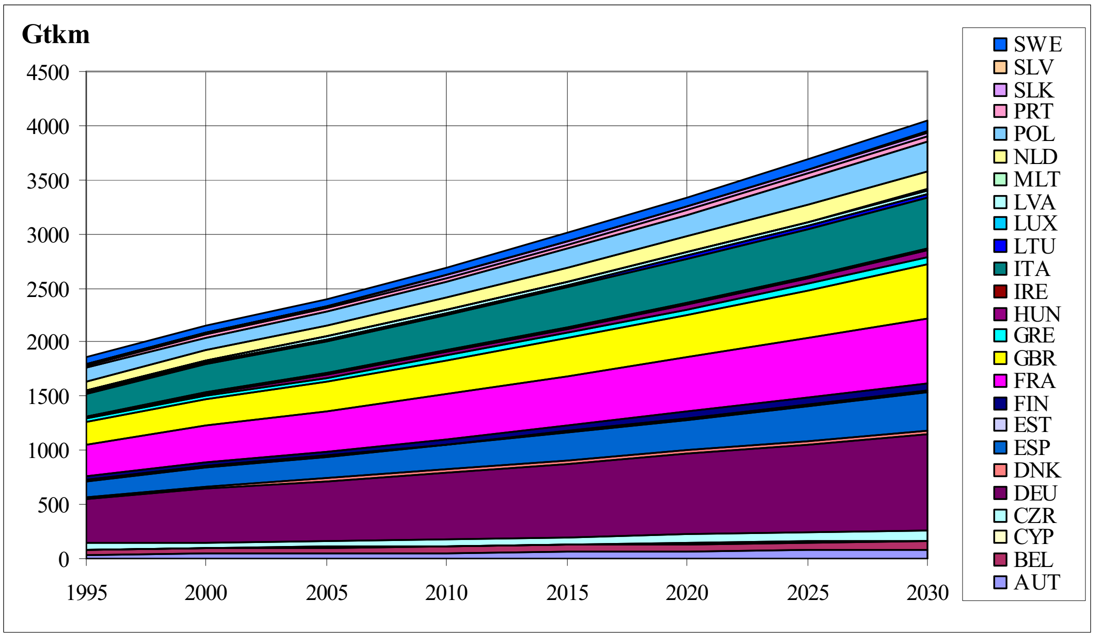
Figure 11 Passenger transport by car in billion passenger km (Gpkm)



Source: PRIMES NCLP scenario

Freight transport grows faster than passenger transport, increasing by 68% over the period 2005 to 2030.

Figure 12 Freight transport in billion tonne km (Gtkm)

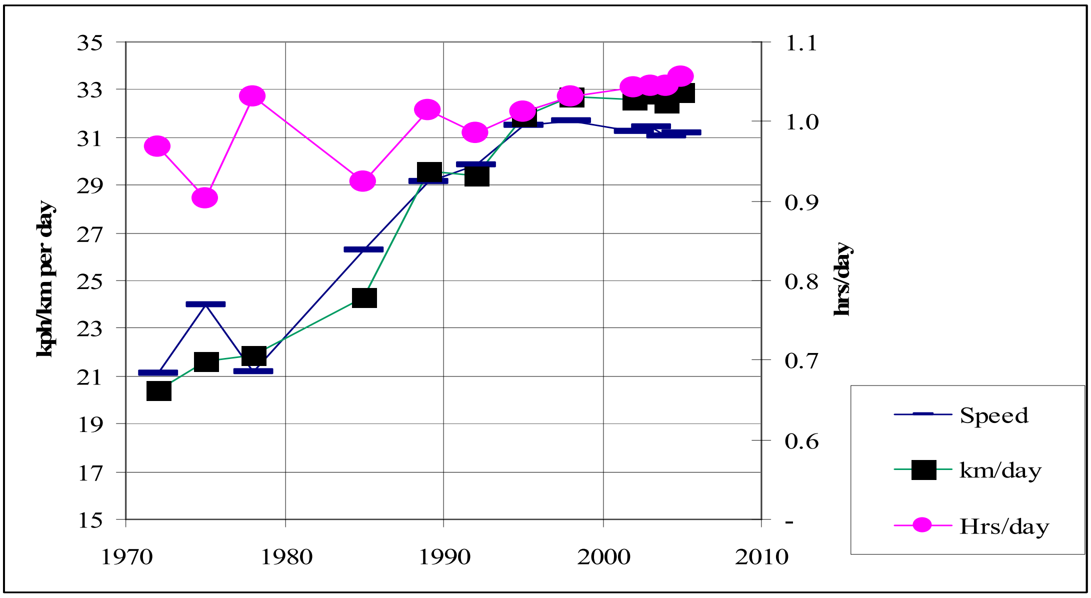


Source: PRIMES NCLP scenario

These exogenous assumptions about transport growth are critical to the prospects for CO_2 emission and for the consumption of fossil liquid fuels for transport, which are the most difficult to replace. The transport demand forecasts used by PRIMES

are made using functions of income, consumer preference and relative prices. These may not fully account for other factors, including saturation effects.
For example, in the UK, travel distance per person per year (excluding international travel) has not changed significantly for the past ten years. It is notable that the average speed of travel and time taken have shown signs of levelling off as is shown in the next Figure. One probable reason for this is greater congestion on the road network. In addition, changes in fundamental drivers such as land use patterns and distance between home and work place. Such effects mean that the functions fitted to past consumption will not necessarily produce accurate forecasts. The UK data suggest that if saturation effects are not accounted for, that the exogenous demand projections used may be too high.

Figure 13 UK passenger travel trends



Source: National Travel Survey (DfT, 2006)

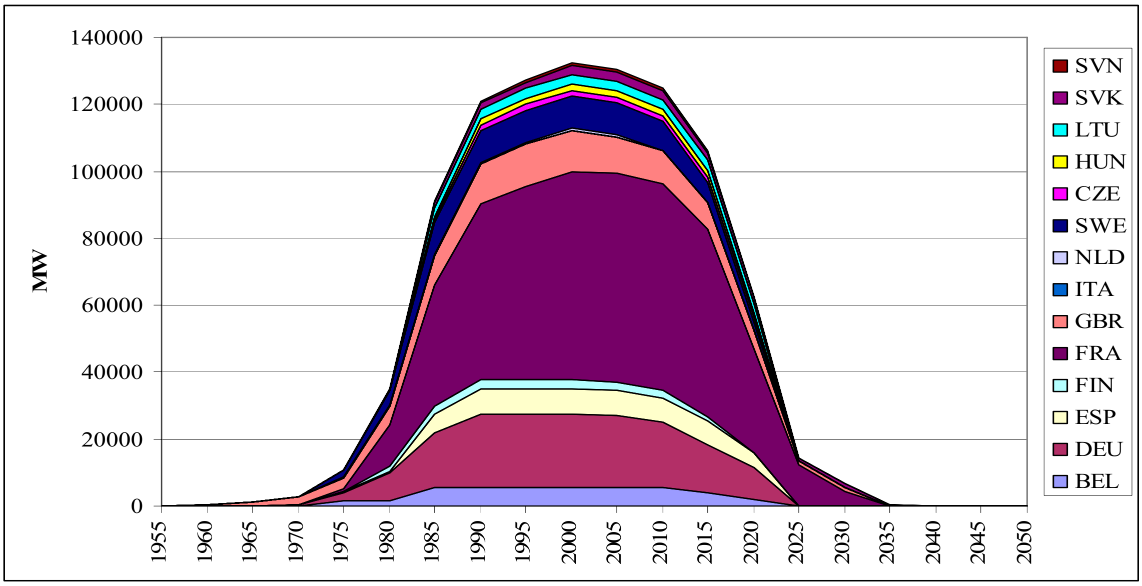
Furthermore, changes to transport demand and its allocation to different modes may be called measures, and can be influenced with instruments such as car restriction, congestion charging, teleworking, etc. For these reasons, to take the PRIMES transport scenarios as exogenous fixed projections means that the full range of measures is not available. Therefore the base demand for transport (passenger kilometres and freight tonne kilometres) is taken from PRIMES, but this may be modified in the scenarios by demand management and modal change.

3.6. Nuclear power

A critical factor determining carbon dioxide emission is the future output from nuclear power stations. Future nuclear output is dependent on three factors: the lifetimes of existing plants; the building and commissioning of new plants; and the performance of the plants. Decisions about nuclear capacity are highly dependent on Government policies, which have been in flux in most EU25 States for some years.

The next Figure shows the historic profile of commissioning in the EU25 countries with a peak rate of commission in the mid 1980s leading to a peak installed capacity around 2000. The operational capacity of existing plant in the future depends on operating lives; and the Figure shows the profile of operating capacity assuming a lifetime of 35 years.

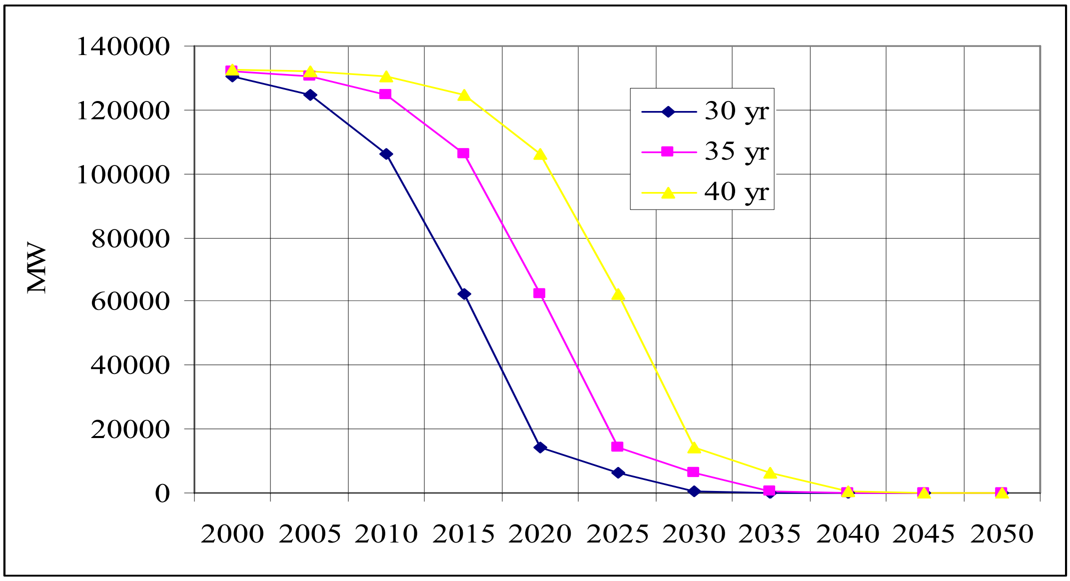
Figure 14 Historical and projected existing nuclear capacity



Source: Platts power plant database, 2007.

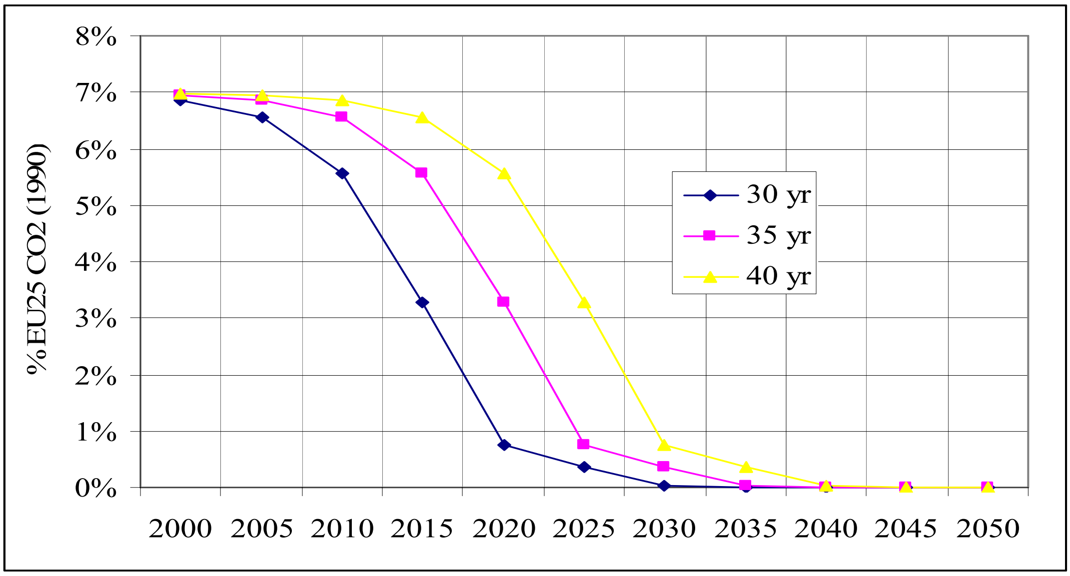
Given that planning and constructing a nuclear power station takes 5-10 years and that it would take a considerable time to ramp up to a programme of parallel station construction, few new stations will be operating by 2020 whatever the assumed government policies. Therefore, for 2020, the most significant parameter is the assumed lifetimes for existing plants. The next Figure depicts the EU25 operational nuclear capacity of existing plants assuming 30, 35 and 40 year lifetimes; the capacity operating in 2020 is 14 GW, 62 GW and 106 GW respectively for these lifetimes.

Figure 15 EU25 nuclear capacity with different lifetimes



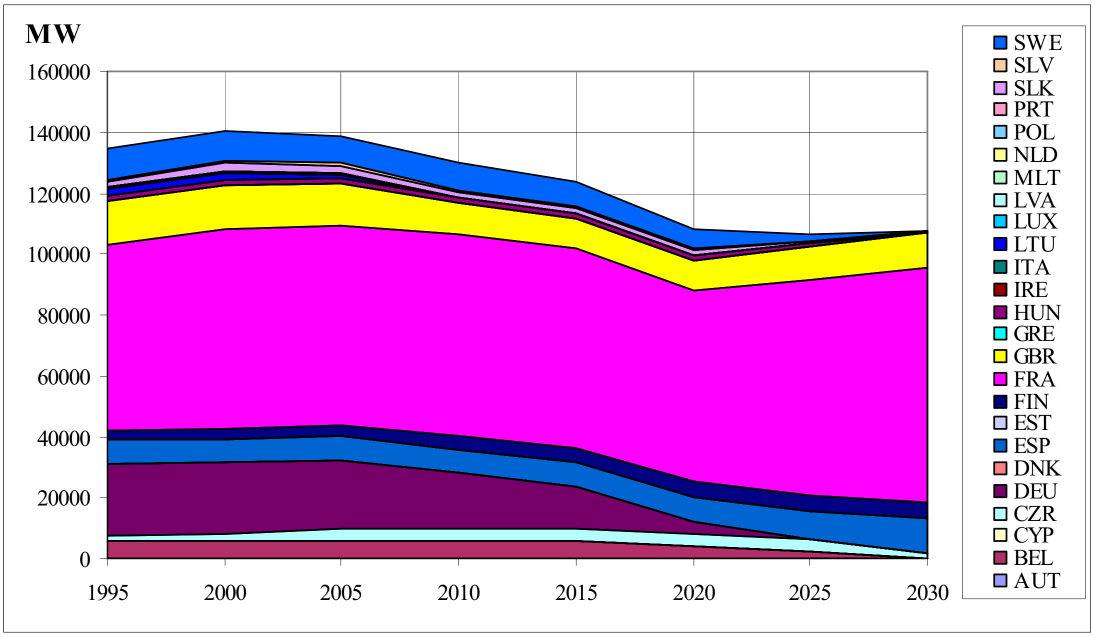
Assuming different lifetimes, the next Figure gives the approximate fractions of EU25 total CO_2 emission avoided using nuclear power, assuming it generates at a 75% annual capacity factor and displaces fossil generation at 0.43 kg CO_2/kWh. This is representative of gas combined cycle gas turbine (CCGT); if it were coal, the emission avoided would be approximately doubled. The fraction ranges from about 0.5% to 5.5% in 2020, so lifetimes and the corresponding generation from existing nuclear power stations are critical for meeting targets in 2020. This suggests there will be a significant effort to extend nuclear station lifetimes.

Figure 16 Avoided CO_2 emission because of nuclear power



The next Figure shows the PRIMES projection of future nuclear capacity by country.

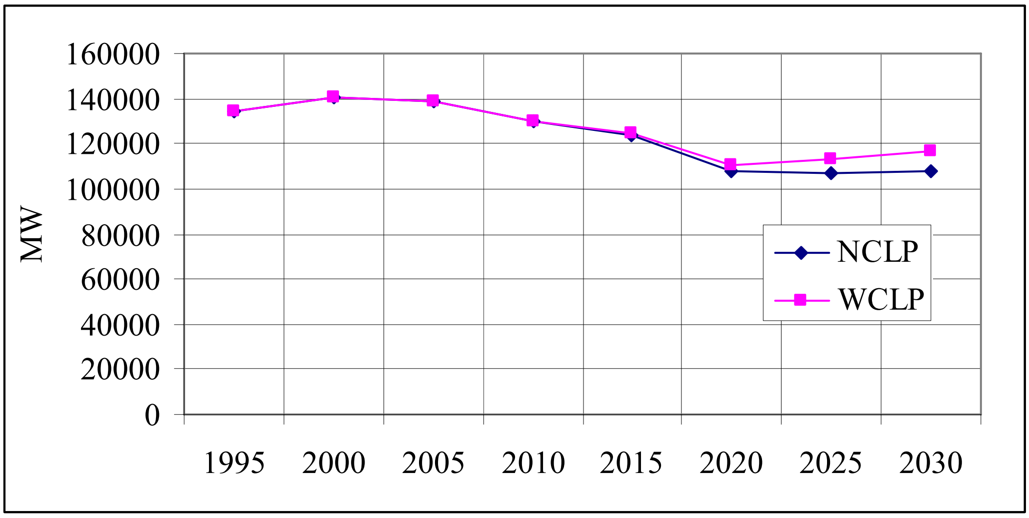
Figure 17 Nuclear capacity projection



Source: PRIMES NCLP scenario

There is slightly more nuclear capacity and generation In the WCLP scenario than in the NCLP scenario. Plainly, the assumptions about nuclear power are critically affect atmospheric emissions.

Figure 18 Nuclear capacity projections

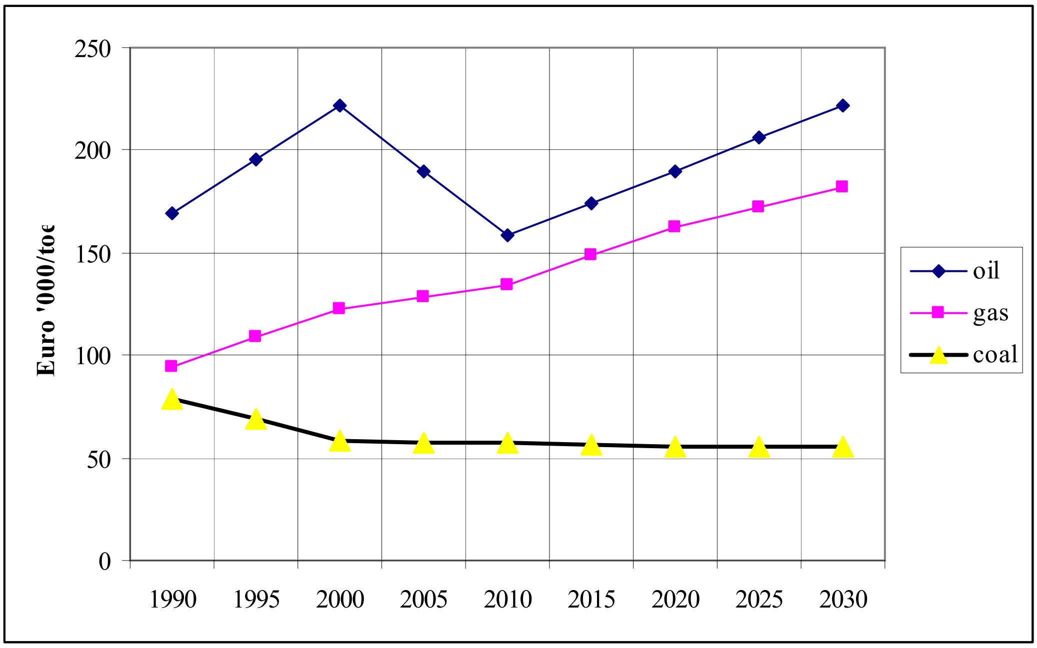


Source: PRIMES NCLP / WCLP scenarios

3.7. International fossil fuel prices

International fuel prices are the same in the NCLP and WCLP scenarios. In reality, the price of a fuel will be higher in a scenario in which more of that fuel is consumed. Accordingly, prices should generally be higher in the NCLP scenario than the WCLP scenario. SEEScen uses fuel prices to calculate the total costs of energy scenarios, but it does not model the effect of fuel prices on outcomes such as transport demand or mode, or generation mix — these are exogenously specified.

Figure 19 International fossil fuel price projections



Source: PRIMES NCLP / WCLP scenarios

4. Emission Control Measures

The general categories of NEOP and EOP emission control measures were set out in Table 1. These are briefly described below and expanded in Table 7.

Behaviour

Behavioural changes relate to demand, and the choice and use of technologies. Travelling less or heating a house to a lower temperature reduces energy consumption and emissions. Choosing the most fuel efficient car currently marketed, will reduce energy use and CO_2 emissions by over 50% as is shown below. Driving vehicles more slowly on motorways could reduce emissions on those roads by 10-20%. In Energy, Carbon Dioxide and Consumer Choice (1992), Barrett gives an overview of some of the behavioural options deployed in the SEEScen model.

Demand management

Demand management is defined as energy savings achieved through measures such as insulation, ventilation control, heat recovery, improved energy system controls, low mass vehicles, and low flow showers. Demand management is applied in the sectors of end use or final consumption, and can apply to new or existing technologies (e.g. an existing building.).

Efficiency of energy conversion

The efficiency of energy conversion is defined as the ratio of useful energy output from a technology to the fuel energy input - it thus refers mainly to energy technologies such as boilers and power stations. Efficiencies can be improved in end use sectors (boilers, cookers, lights etc.) and in energy supply (power stations, refineries etc.). The potential efficiency gains of technologies in general vary according to the fuel used. For example, the potential improvement in efficiency for electric water heating is assumed to be 15%, less than the 30-50% which might be expected for water heating with oil.

Fuel switching

Changing the mix of fuels supplied directly to consumers and to the producers of secondary fuels such as electricity and heat can reduce carbon emissions. This may be done in two ways:

- Switching to inherently lower carbon fuels: the order of carbon emission per energy content is renewable and nuclear (zero), and then fossil natural gas, petroleum and coal.
- Switching to delivered fuels which reduce emissions from the energy system as a whole. This includes switching from electricity to gas where marginal electricity supply is from fossil fuelled electricity only (i.e. non cogeneration) stations; switching to heat where heat is supplied by cogeneration or efficient heat only plant.

The amount of switching possible is limited by the technical and economic potential for different energy forms in different countries, and the rate at which energy mixes may be changed.

To implement the policy options to different degrees in the scenarios, decision variables are set and are input to SEEScen. Some decision variables control several measures. For example: the decision variable BePMod in the Table below controls the modal mix of passenger transport, and shifting a fraction of passenger km from car to bus and rail; FMSup controls the change in fuel supply mix covering all fossil and renewable fuels.

Table 7 Emission control measures and decision variables

Class	Examples of measures	Rate yrs	Decision variable name
Behaviour	Effective comfort temperature in buildings	10	BeTi
	Passenger transport demand management	20	BeTPass
	Aviation transport demand management	15	BeAvi
	Passenger mode; from car to bus/rail	20	BePMod
	Freight mode; from truck to rail	25	BeFMod
	Downsizing cars	15	BeCar
	Speed reductions on motorways, aircraft	5	BeSpeed
Demand management	Transport load factor	20	DMTLF
	Demand management in transport	30	DMTra
	Building insulation and ventilation control	40	DMBui
	Demand management in non-residential sectors	30	DMInd
Fuel mix	Shift to electric vehicles, CHP and renewables in end use sectors	35	FMDel
	Shift to CHP and renewables in supply sectors	40	FMSup
Efficiency	Improved efficiency of boilers, heat pumps, etc	35	EFDel
Pollution	Flue gas desulphurisation, catalytic converters	30	PoAll

In these scenarios, non-biological carbon sequestration, such as the storage of carbon in exhausted oil or gas reservoirs, is excluded as an option. This is because it impairs energy efficiency, increases primary CO_2 emission and is costly. There is a potential risk of leakage. These aspects need further research, but the scenarios developed here indicate that sequestration is not required to achieve large CO_2 reductions in Europe.

4.1. Scenario assumptions

The measures of demand management (DM), end use efficiency (EE), end use fuels switch (ES), fuel supply efficiency (FE) and fuel supply fuel switch (FS) are implemented to different degrees in each country. Judgements about the levels of implementation of measures were made according to:

- •What is required in order to meet EU25 targets. This is the most important consideration.
- The degree to which the NEOP measures have already been applied
- The potential for further application of NEOP measures.

There are two problems applying the carbon emission reduction options in scenarios; knowing accurately what the current situation is, and making assumptions about how much these may be applied in the future.
There is no comprehensive database for Europe covering details such as:

- The size and heat loss characteristics of domestic and non-domestic buildings.
- The average operating efficiencies of boilers, lights, electric motors, power stations, etc.

Therefore there is uncertainty in the starting point of the scenarios, and this leads to uncertainty in future possibilities. If, for example, there are already high levels of insulation in buildings, then future savings will not be large.

The best performance of most technologies is similar across all countries. The maximum efficiency of a gas boiler or a light bulb may be assumed to be the same in Sweden as in Spain. The performance of some technologies, such as heat pumps and solar collectors, is affected by the climate in which they operate, and this varies from country to country.

The potential use of renewable energy resources in each country is uncertain because:

- Data are poor for some countries and some resources.
- The amount of energy that may be extracted depends on:
  - The marginal costs, which increase steeply with amount extracted. For example; the cost of wind electricity might double going from a high wind speed onshore site to a distant off-shore site.
  - The environmental impacts, which vary widely. For example; the use of biomass waste for CHP might have net environment benefits whereas growing energy crops can have impacts such as decreased biodiversity or increased water use and pollution.

In any case, it should be recognised that the cost effective scope of the measures, and the rate at which they might be introduced are not fixed values – they can vary widely according to the context of the scenarios. For example:

- The scope for gas substitution in one country will depend on the overall balance of supply and demand in the EU (and indeed elsewhere in Europe and Asia).
- The lifetime of a coal power station will depend, inter alia, on any targets for atmospheric emissions – with tight SO_2, NO_x and CO_2 emission limits, the life might be 25 rather than 40 years as earlier replacement with alternative generation becomes more cost effective.

- The cost effectiveness of end use efficiency depends on the costs of supply, which are scenario dependent. The higher the cost of energy supply, then the greater increase in end use efficiency is economically justifiable.
- Further improvements in technologies may be expected, the speed and extent of which will depend on factors including policy context. For example, the expansion and development of renewable electricity sources in the UK has been accelerated by the requirement that a certain fraction of electricity should be derived from non fossil fuel sources.

These comments should be borne in mind when considering the assumptions input to the scenarios concerning cost effective potential for energy efficiency and fuel switching, and the rates of turnover and change assumed for the technologies.

Information on the technical scope and economic potential of the NEOP measures explored in the scenarios is drawn from a large number of sources. To comprehensively update the information on the measures for each of the EU25 countries is a worthwhile endeavour, but it is beyond the scope of this exercise. Therefore the assumptions about the measures are taken as typical for the EU. From the perspective of EU25 carbon emission, it is important these values are reasonable for the 'Big Six' countries as they so dominate total emission.

There is general support for the feasibility of the scenarios in other studies done, for example the European Commission published its *Action Plan for Energy Efficiency: Realising the Potential* (CEC, 2006a) which said:

> *The 2006 Spring European Council called for the adoption as a matter of urgency of an ambitious and realistic Action Plan for Energy Efficiency, bearing in mind the EU energy saving potential of over 20% by 2020.*

4.2. Rate of implementation of measures

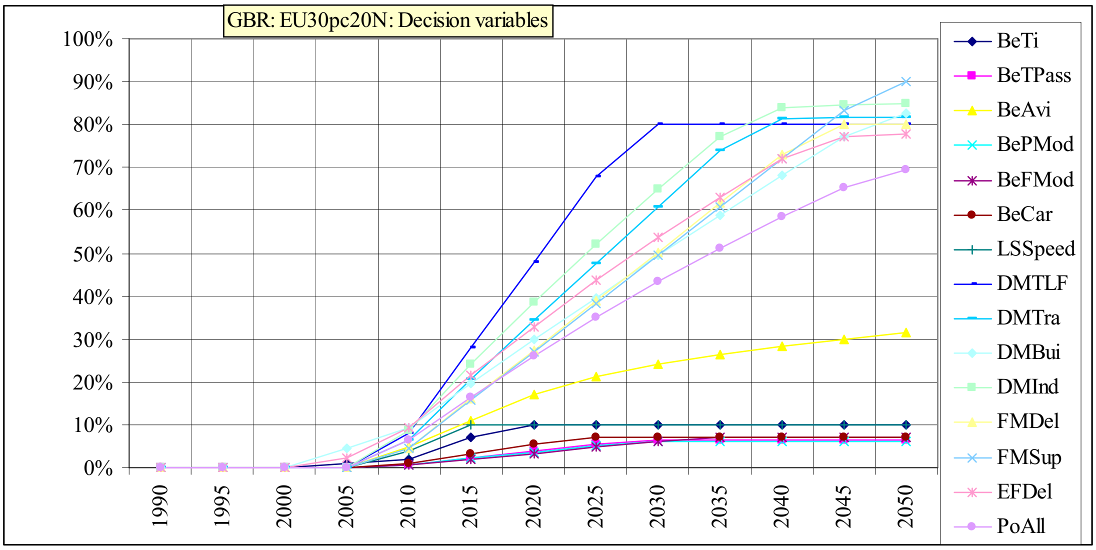
A key issue in this exercise is the rate at which the carbon reduction measures can be introduced; there are only 12 years from the earliest possible introduction of extra measures (2008) to the target year (2020). Table 7 summarises the rates of introduction for the options if average 'natural' technology lifetimes assumed. These points should be noted:

- Some technologies have technical lifetimes determined by practically irreversible breakdown, such as a light bulb. For some the lifetime is determined whether it is cheaper to repair or replace.
- It is generally possible to introduce a measure faster than its natural replacement rate, and usually this is done to realise net savings because of fuel or emission reduction cost savings outweigh the extra capital cost of premature replacement.
- Most technologies (e.g. buildings, power stations, cars) are in fact composites of components with different lives, some of which it may be cost-effective to upgrade or replace individually, without replacing the entire

technology. This is particularly so for buildings, composed of elements with a wide range of lifetimes: walls (100s of years), windows (30 years), heating systems (20 years). In this instance, it is (arbitrarily) assumed in the scenarios that insulation is retrofitted at a turnover rate of 40 years which is faster than programmes in the UK, but slower than that in Germany.

The decision variables are increased with logistic curves to their maximum value for any particular scenario at the rates tabulated, as illustrated in the next Figure. The decision variables labels are given in Table 7. The maximum values for the measures generally vary from scenario to scenario.

Figure 20 Measures introduction with decision variables (GBR)



5. Results

The SEEScen model was run for all 25 EU countries, and for six scenarios for comparison. It is not possible to present detailed results for every sector and country in this report, as there would be some 100 tables and graphs for each EU25 country. Therefore sample material is given for selected sectors and countries. Because European demands are reasonably homogeneous, this selected material will indicate general trends, though the modelled results depend on details of each country's climate, population, renewable resources, etc.

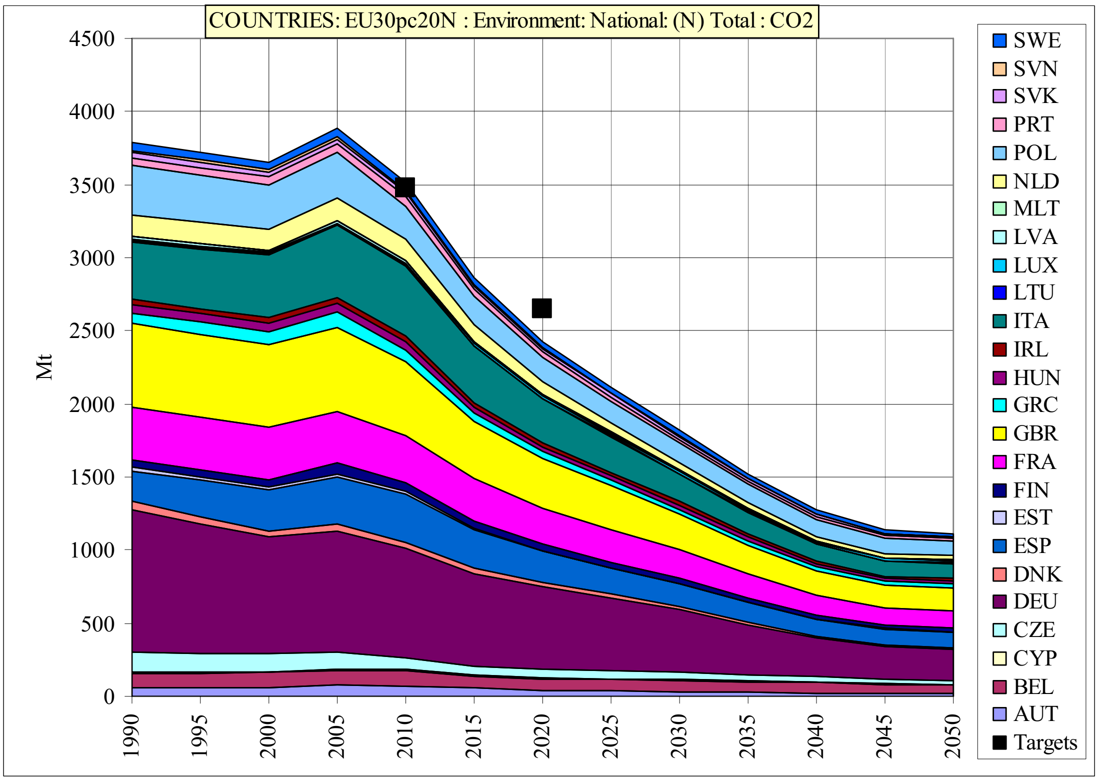
Note that:

- Only CO_2 emissions from fossil fuel use for energy are included. In these graphs, CO_2 emissions are normalised to PRIMES data up to 2000.
- International transport (bunker fuel) CO_2 emissions are excluded from national results simply because they are currently excluded from the Kyoto protocol. However, bunker fuel use is included in energy flows as they are part of national energy systems. A separate section discusses international transport issues.
- The historical IEA energy statistics are sometimes difficult to interpret, particularly concerning electricity and heat generation from public and autoproducer electricity only and combined heat and power stations. In places this leads to erratic historical trends.

5.1. European Union results

Figure 21 shows the carbon emission for the EU25 countries in the EU30pc20N scenario. The black squares show the Kyoto target for 2010 (but note that this does not just apply to CO_2) and the 30% target for 2020. In the projection, the EU25 fails to meet the Kyoto target in 2010 for CO_2, but then emissions fall steeply such that the 30% target in 2020 is met with a margin — the reduction is 36%. One notable feature is that EU25 carbon emissions are still falling steeply after 2020, this is because the measures take time to fully affect the stock of technologies. This means that the scenarios are quite robust. The reader is reminded that these results would be different if other GHG and measures in other countries such as FlexMex were included.

Figure 21 EU25 countries carbon emission: SEEScen EU30pc20N scenario



5.2. Country by country CO_2 emission

The following sequence of Figures gives the sectoral carbon emission for each of the EU25 countries for the EU30pc20N scenarios. Note that there are some problems with historical energy data and the allocation of CO_2 emissions with the most important being:

- The allocation of energy and emissions for electricity generation and public CHP. Some historical IEA data for certain countries have apparent problems, e.g. for Poland.
- The allocation of diesel fuel to passenger cars, freight trucks and light duty vehicles (LDVs) is estimated and so are emissions. The partitioning varies widely between countries.

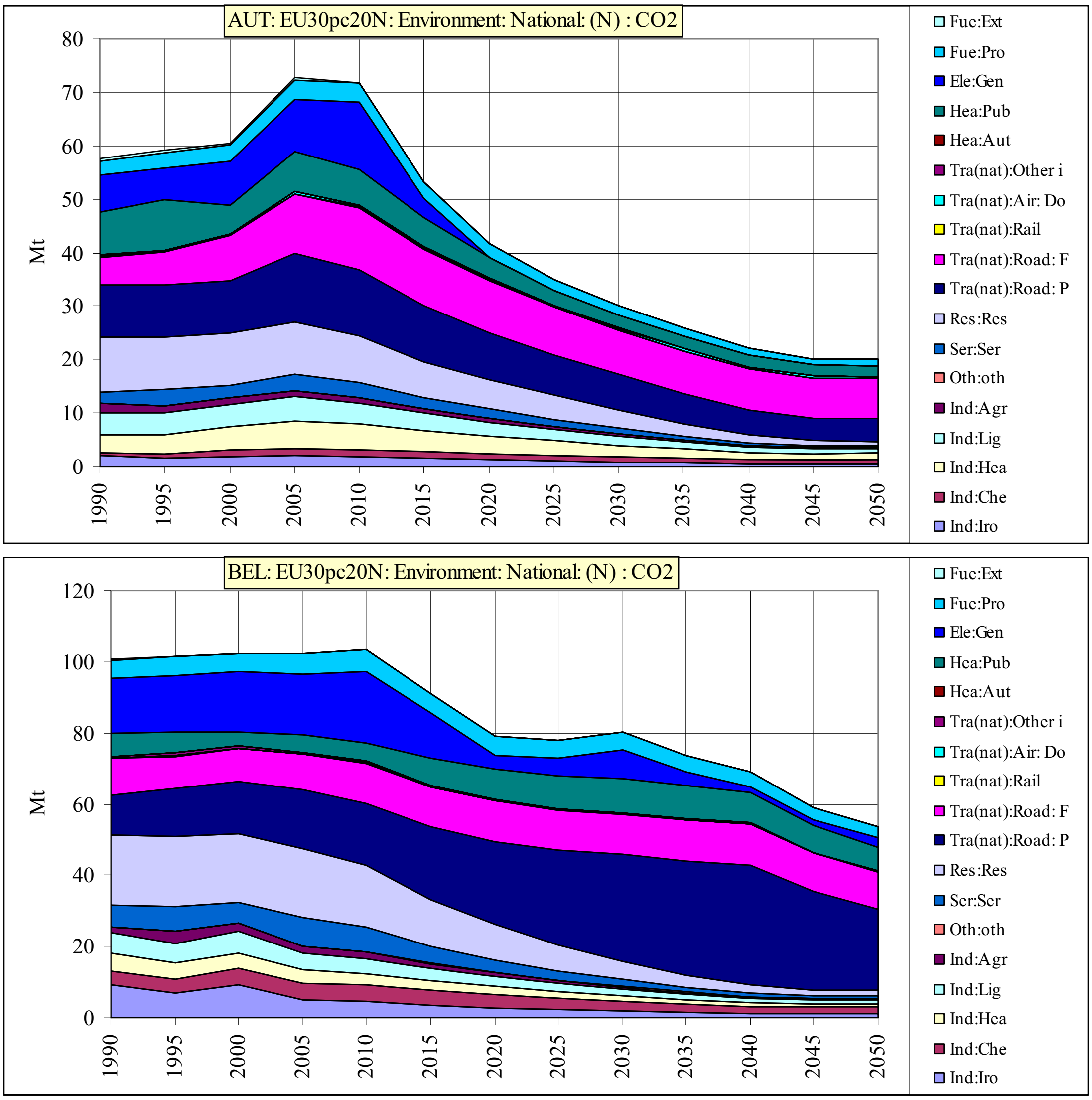
The Table below summarises the graph labelling.

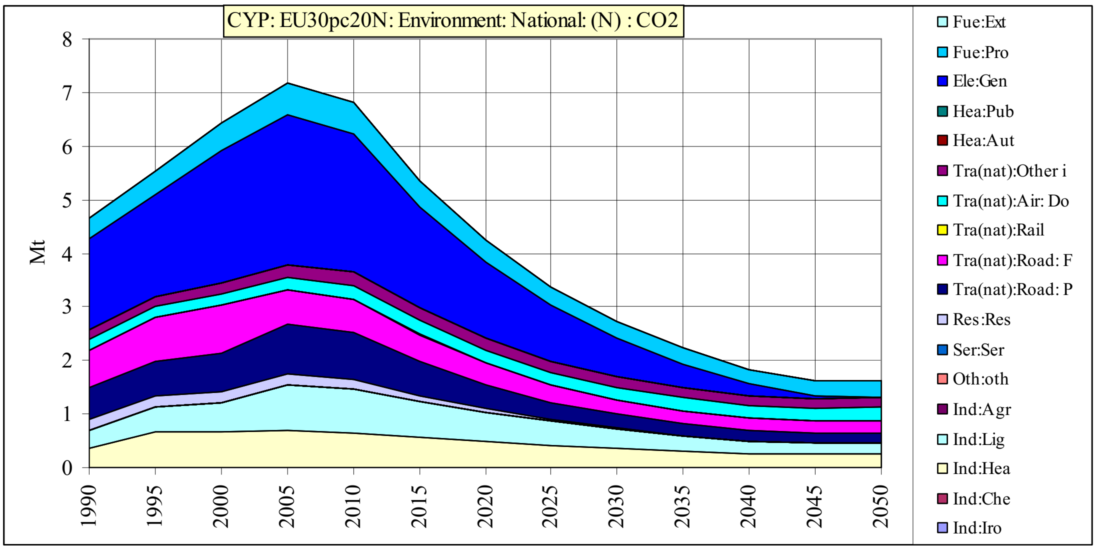
Table 8 Country CO_2 labelling

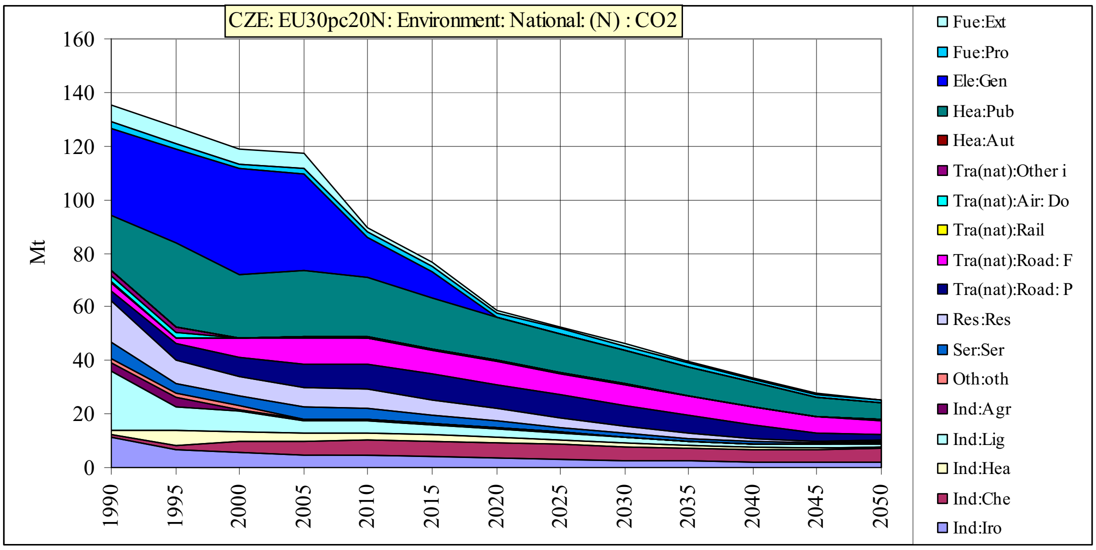
Sector	Sub-sector	Label
Industry	Iron and steel	Ind:Iro
	Chemical	Ind:Che
	Heavy	Ind:Hea
	Light	Ind:Lig
	Agriculture	Ind:Agr
Other		Oth:oth
Services		Ser:Ser

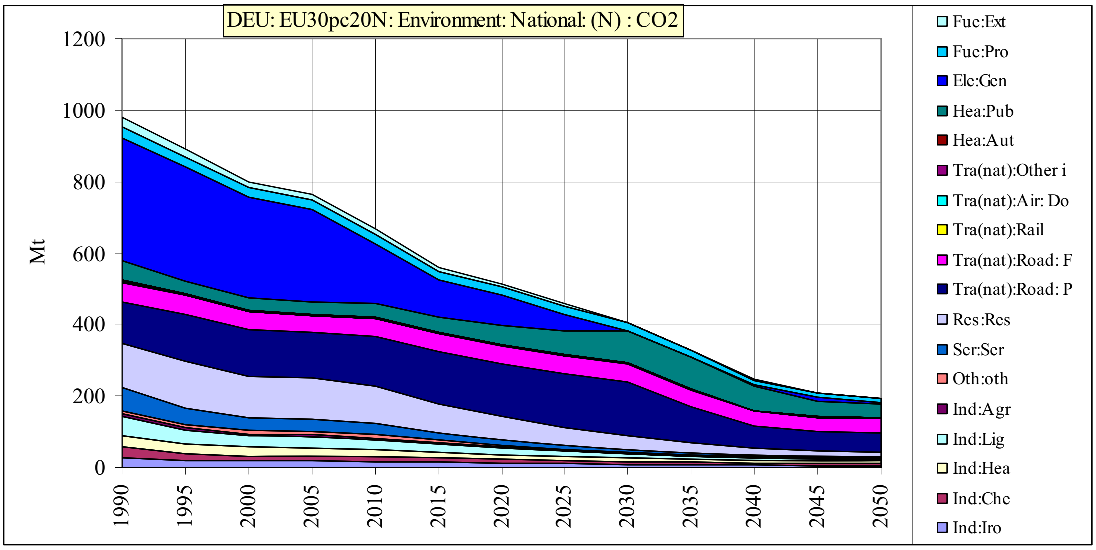
Residential		Res:Res
Transport (national)	Road passenger	Tra(nat):Road: P
	Road freight	Tra(nat):Road: F
	Rail	Tra(nat):Rail
	Air domestic	Tra(nat):Air: Do
	Inland water	Tra(nat):Other i
Heat supply	Auto	Hea:Aut
	Public	Hea:Pub
Electricity	Transmission	Ele:Tra
	Pumped storage	Ele:Pum
	Generation	Ele:Gen
Fuel	Processing	Fue:Pro
	Extraction/distribution	Fue:Ext

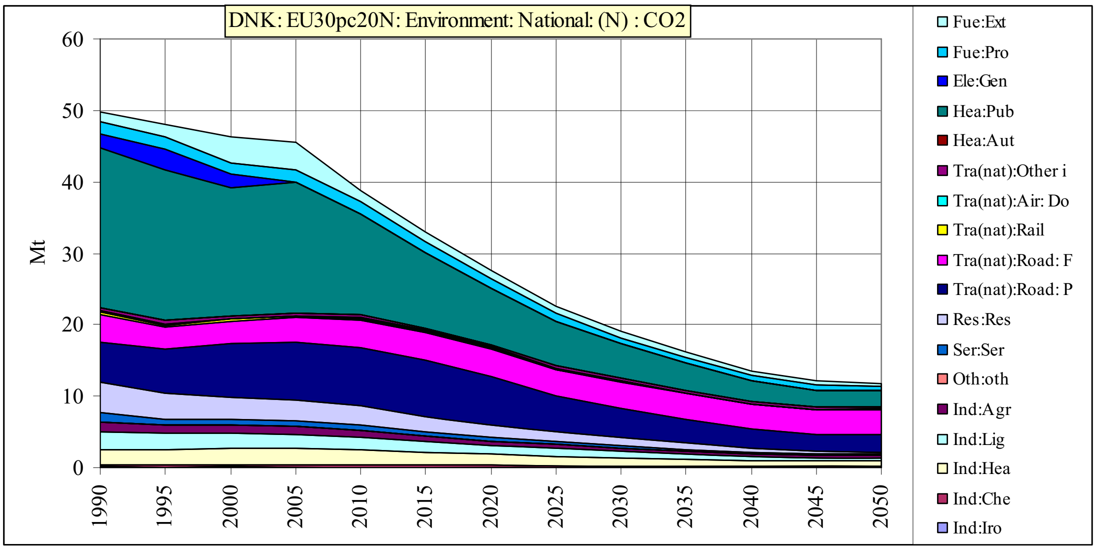
Figure 22 EU25 country by country CO$_2$ emissions: EU30pc20N

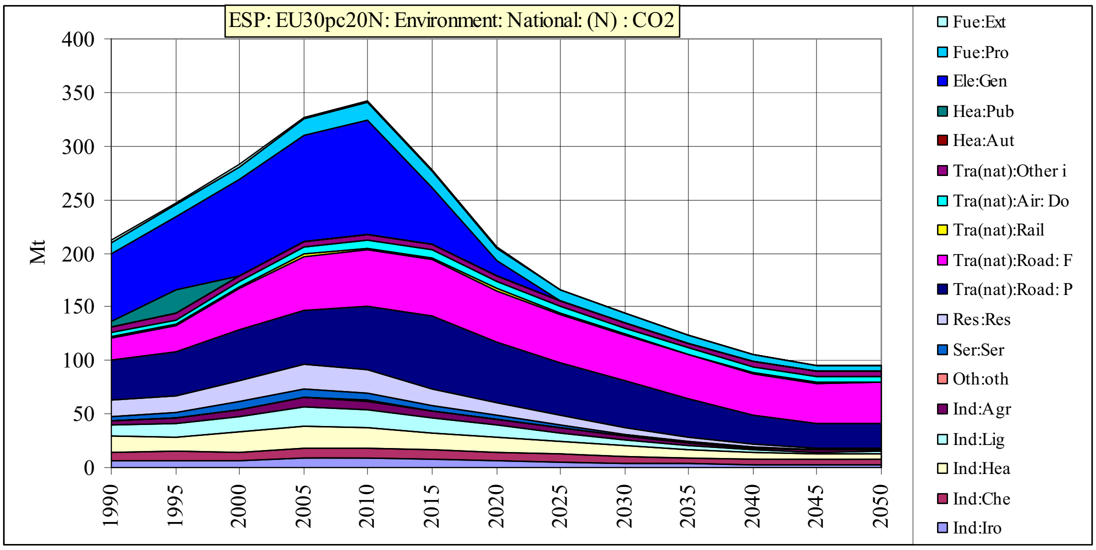


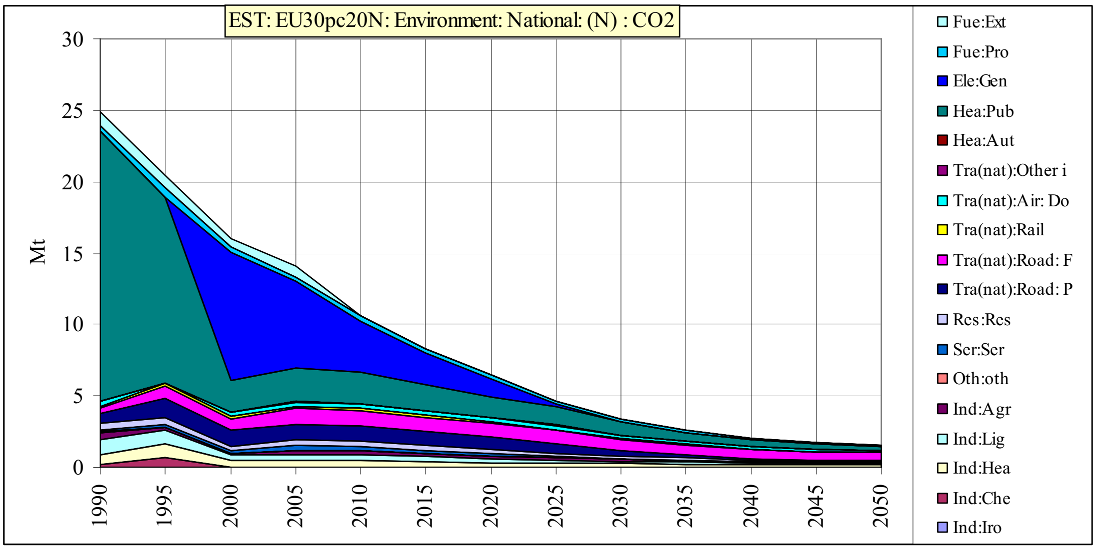

CYP: EU30pc20N: Environment: National: (N) : CO2
Mt
0
1
2
3
4
5
6
7
8
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro

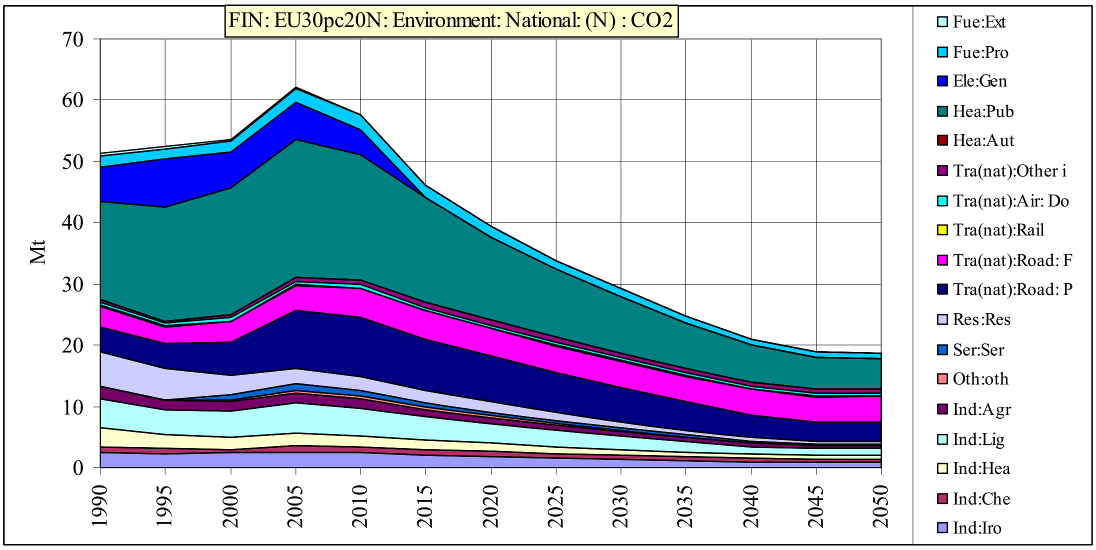

CZE: EU30pc20N: Environment: National: (N) : CO2
Mt
0
20
40
60
80
100
120
140
160
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


DEU: EU30pc20N: Environment: National: (N) : CO2
Mt
0
200
400
600
800
1000
1200
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


DNK: EU30pc20N: Environment: National: (N) : CO2
Mt
60
50
40
30
20
10
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


ESP: EU30pc20N: Environment: National: (N) : CO2
Mt
400
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


EST: EU30pc20N: Environment: National: (N) : CO2
Mt
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


FIN: EU30pc20N: Environment: National: (N) : CO2
Mt
70
60
50
40
30
20
10
0
1990
1995
2000
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2025
2030
2035
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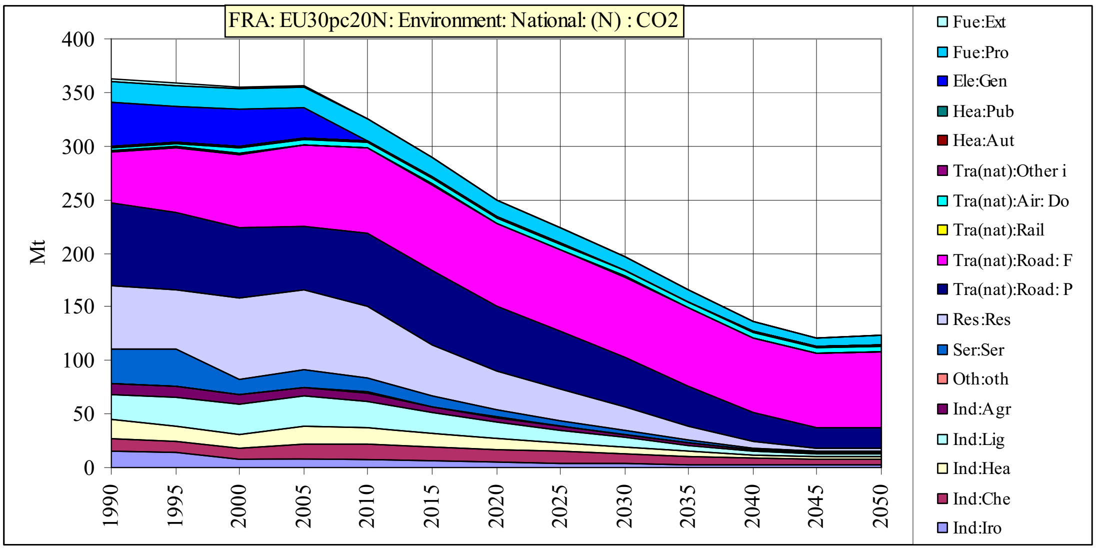
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


FRA: EU30pc20N: Environment: National: (N) : CO2
Mt
400
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
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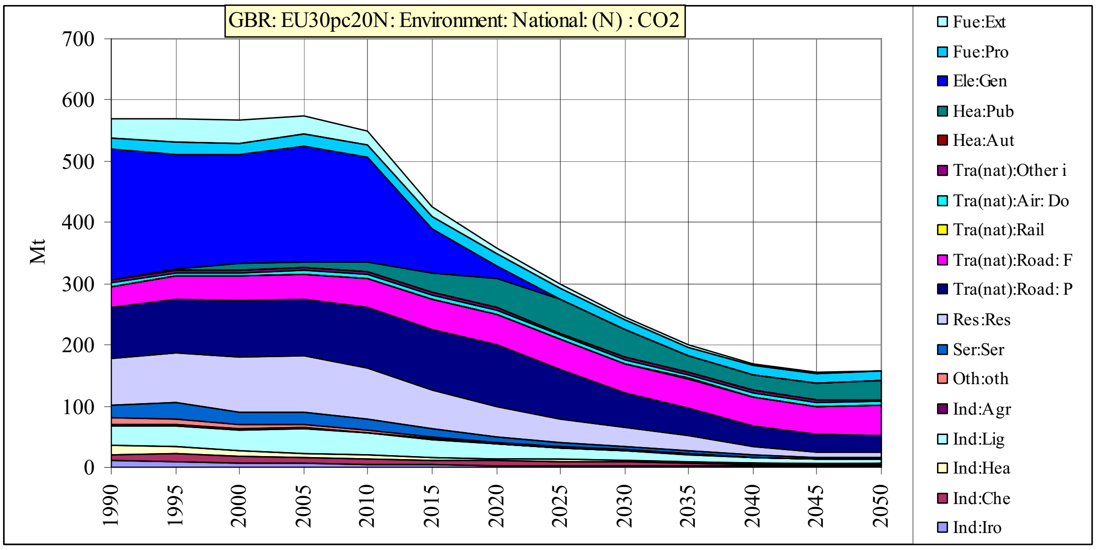
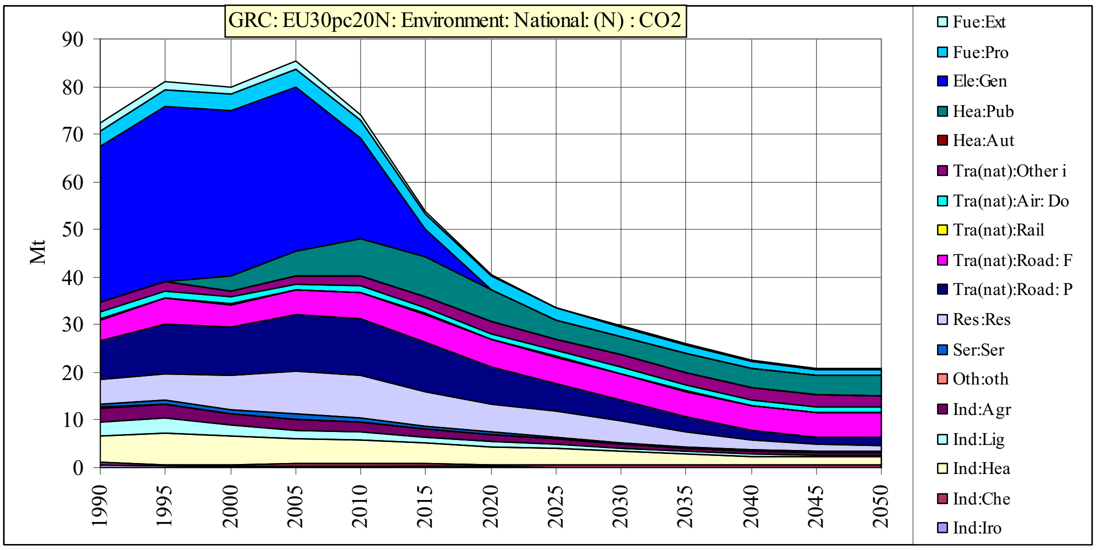
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


GBR: EU30pc20N: Environment: National: (N) : CO2
Mt
700
600
500
400
300
200
100
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


GRC: EU30pc20N: Environment: National: (N) : CO2
Mt
90
80
70
60
50
40
30
20
10
0
1990
1995
2000
2005
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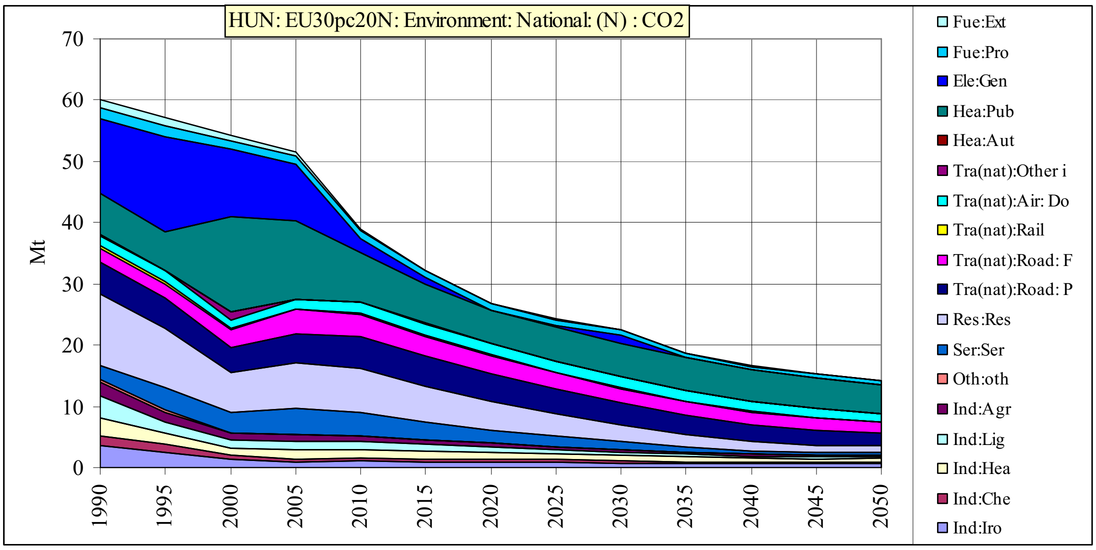
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


HUN: EU30pc20N: Environment: National: (N) : CO2
Mt
70
60
50
40
30
20
10
0
1990
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2020
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2030
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2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
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Oth:oth
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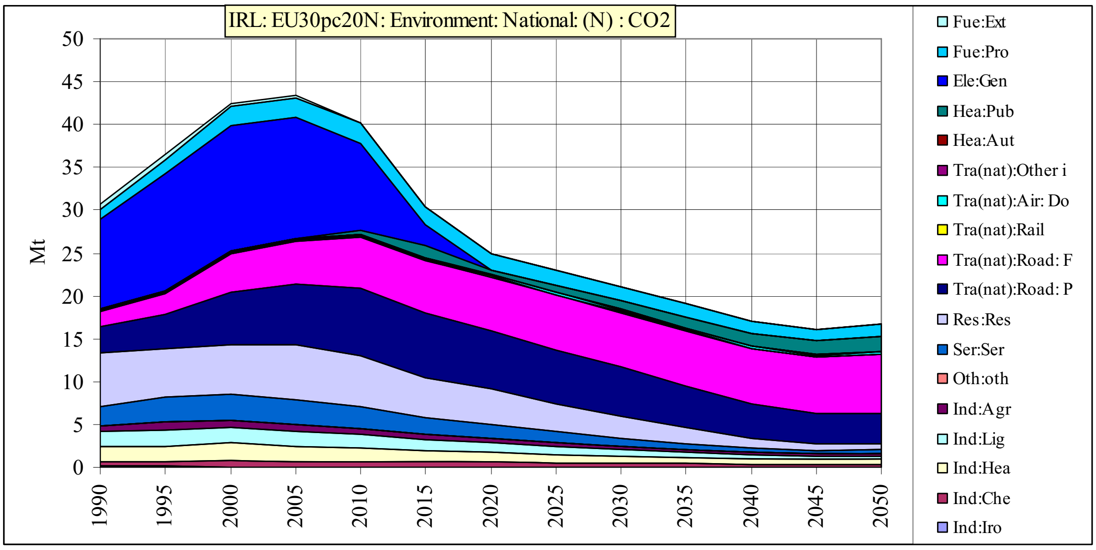
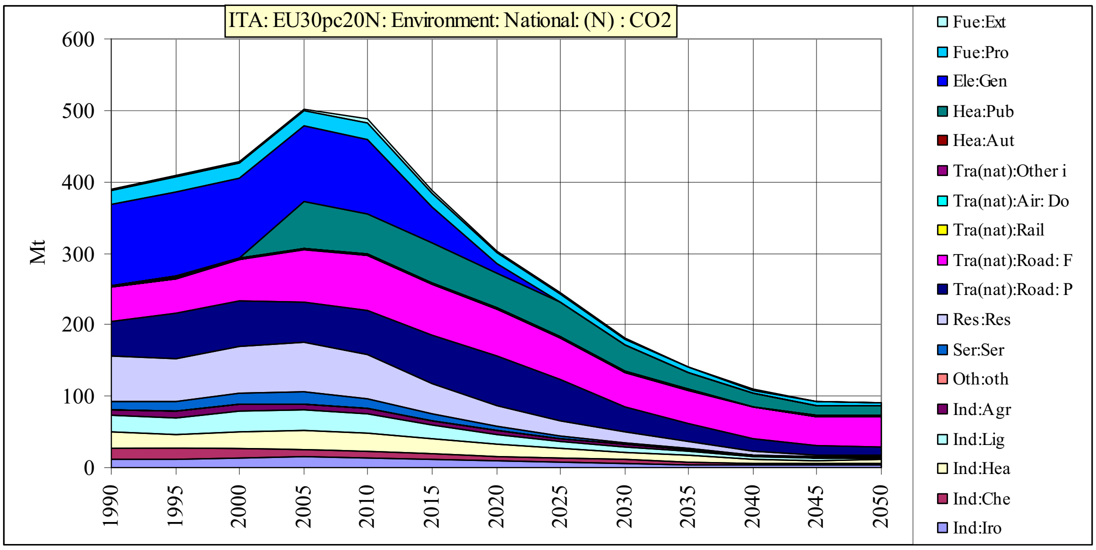
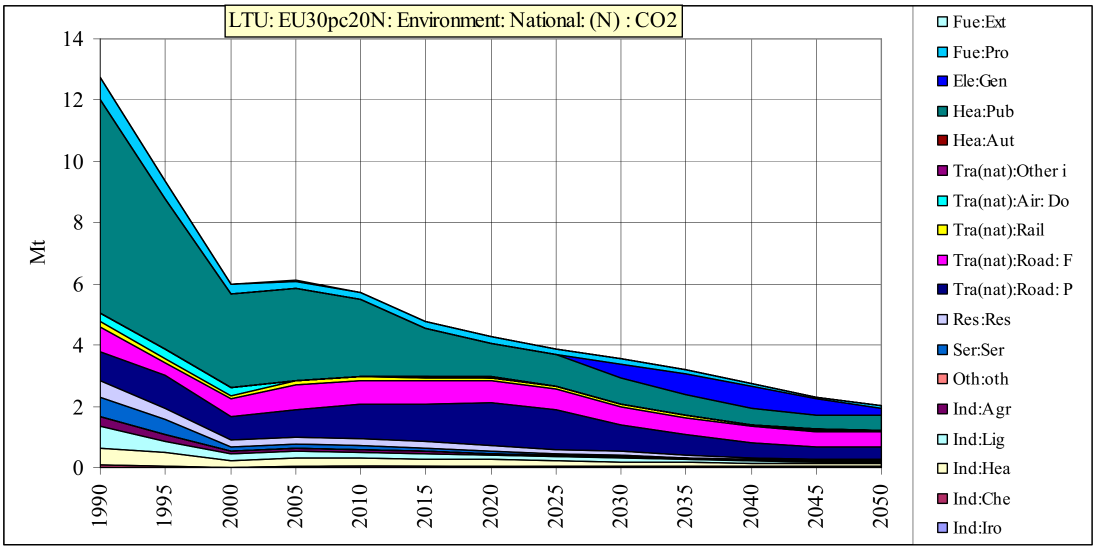
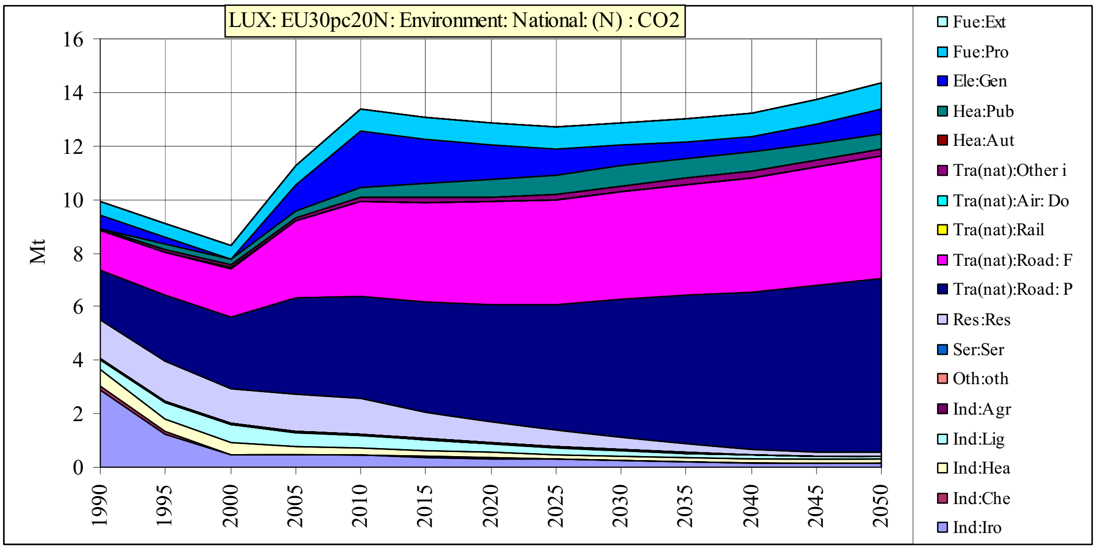
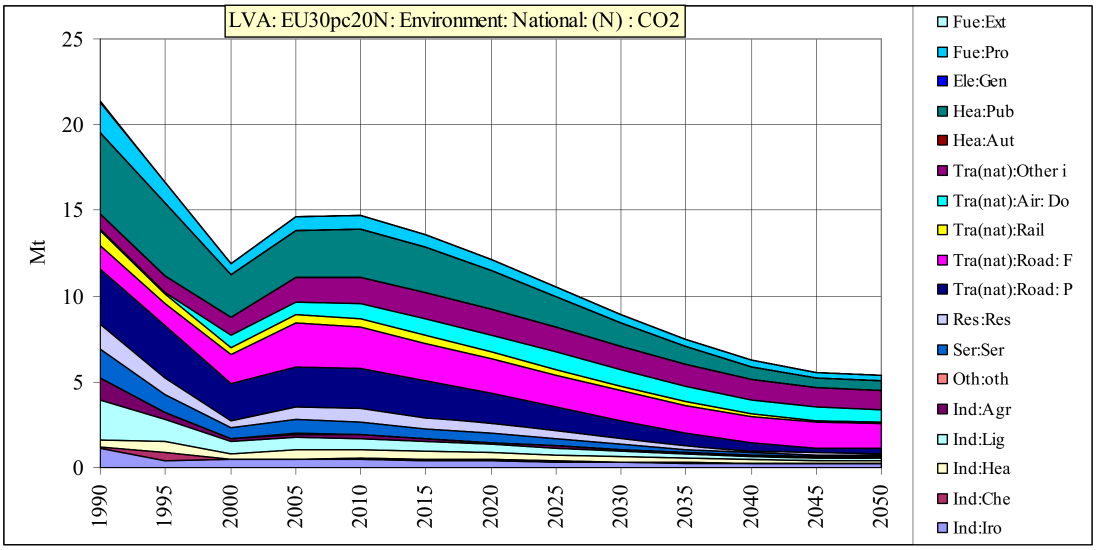
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro

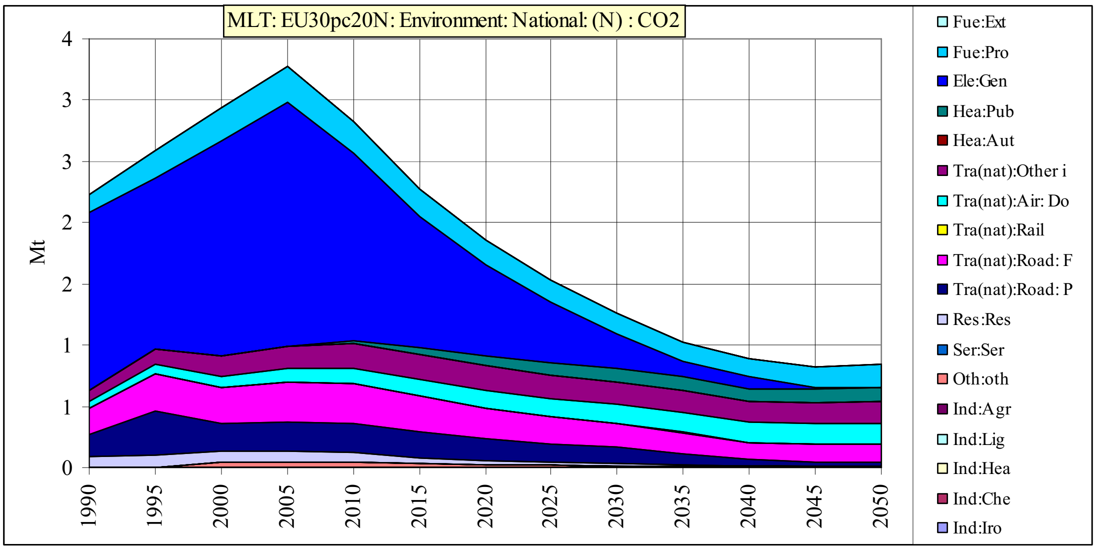

IRL: EU30pc20N: Environment: National: (N) : CO2
Mt
50
45
40
35
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro

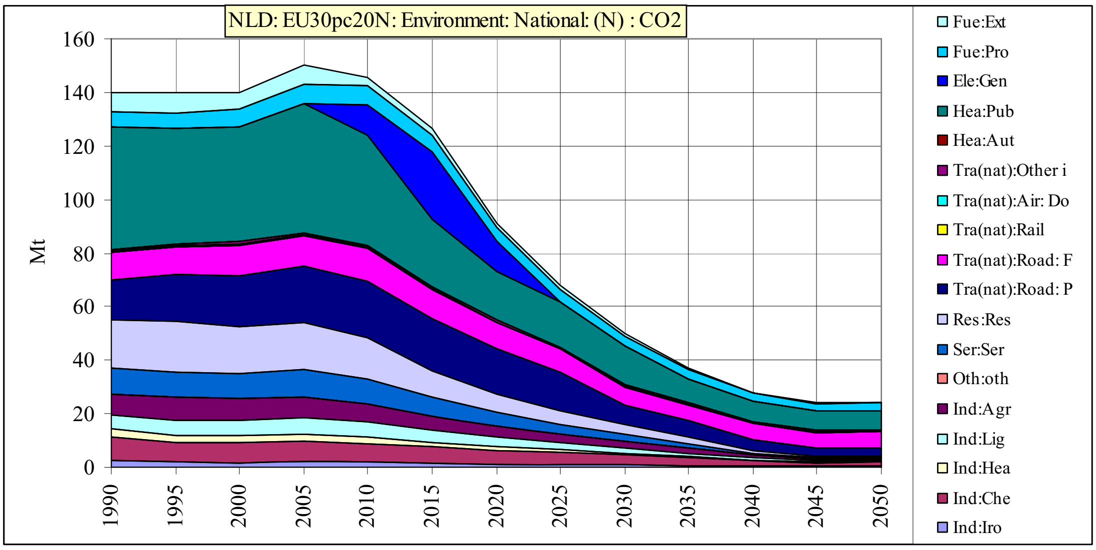

ITA: EU30pc20N: Environment: National: (N) : CO2
Mt
600
500
400
300
200
100
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


LTU: EU30pc20N: Environment: National: (N) : CO2
Mt
14
12
10
8
6
4
2
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


LUX: EU30pc20N: Environment: National: (N) : CO2
Mt
16
14
12
10
8
6
4
2
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


LVA: EU30pc20N: Environment: National: (N) : CO2
Mt
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


MLT: EU30pc20N: Environment: National: (N) : CO2
Mt
4
3
3
2
2
1
1
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


NLD: EU30pc20N: Environment: National: (N) : CO2
Mt
160
140
120
100
80
60
40
20
0
1990
1995
2000
2005
2010
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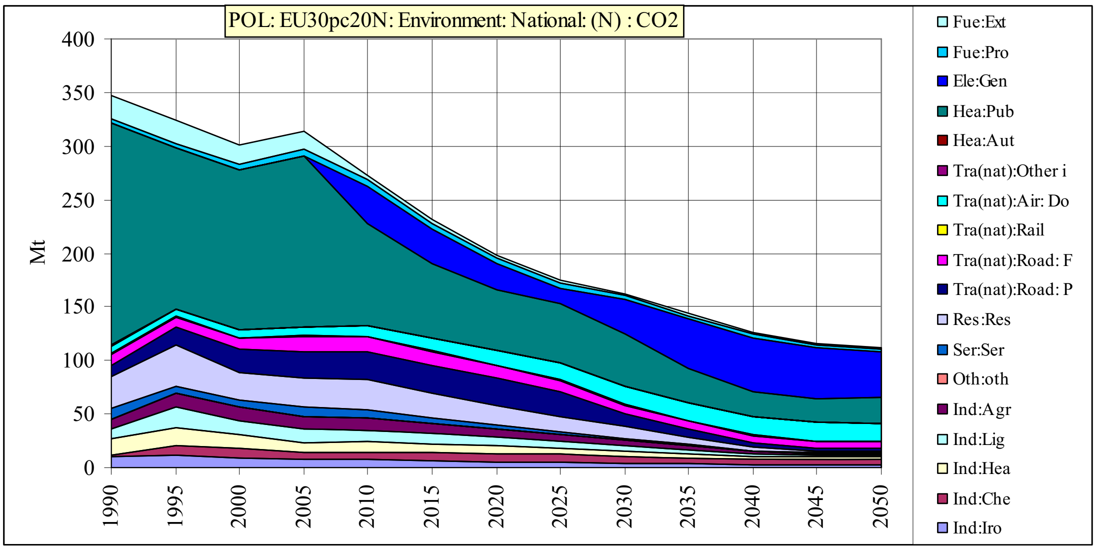
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


POL: EU30pc20N: Environment: National: (N) : CO2
Mt
400
350
300
250
200
150
100
50
0
1990
1995
2000
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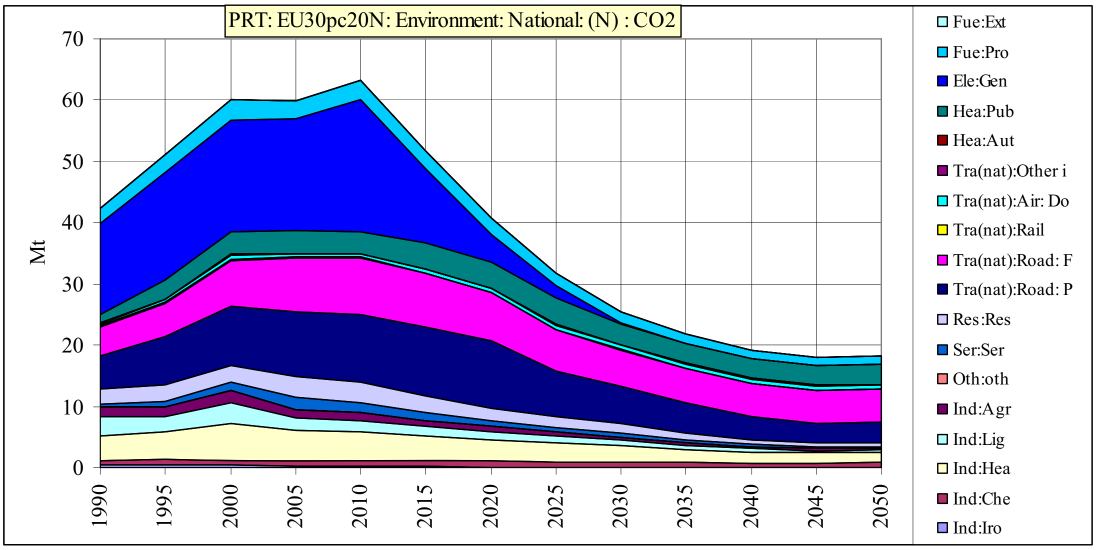
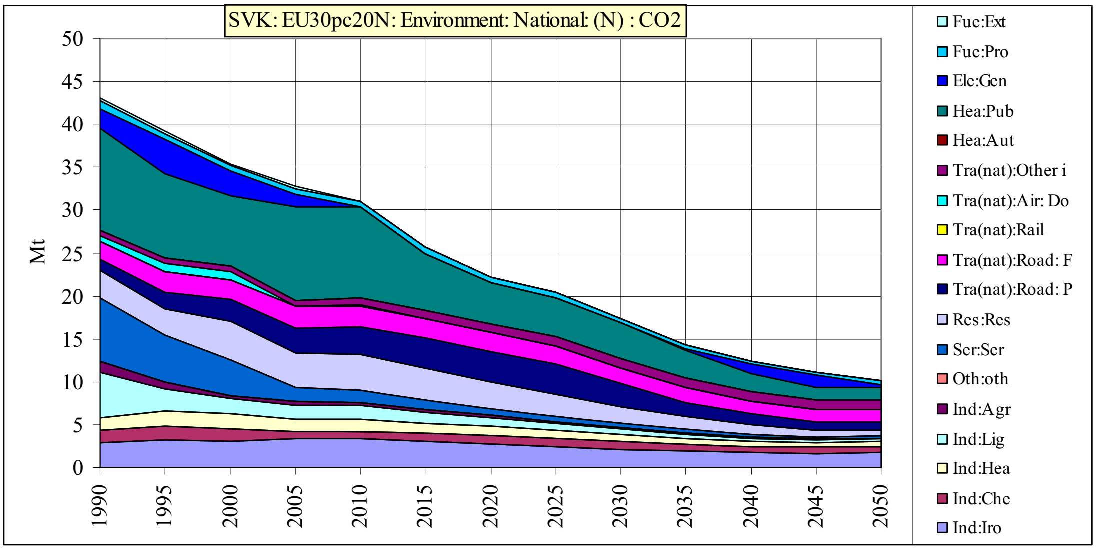
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


PRT: EU30pc20N: Environment: National: (N) : CO2
Mt
70
60
50
40
30
20
10
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro


SVK: EU30pc20N: Environment: National: (N) : CO2
Mt
50
45
40
35
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
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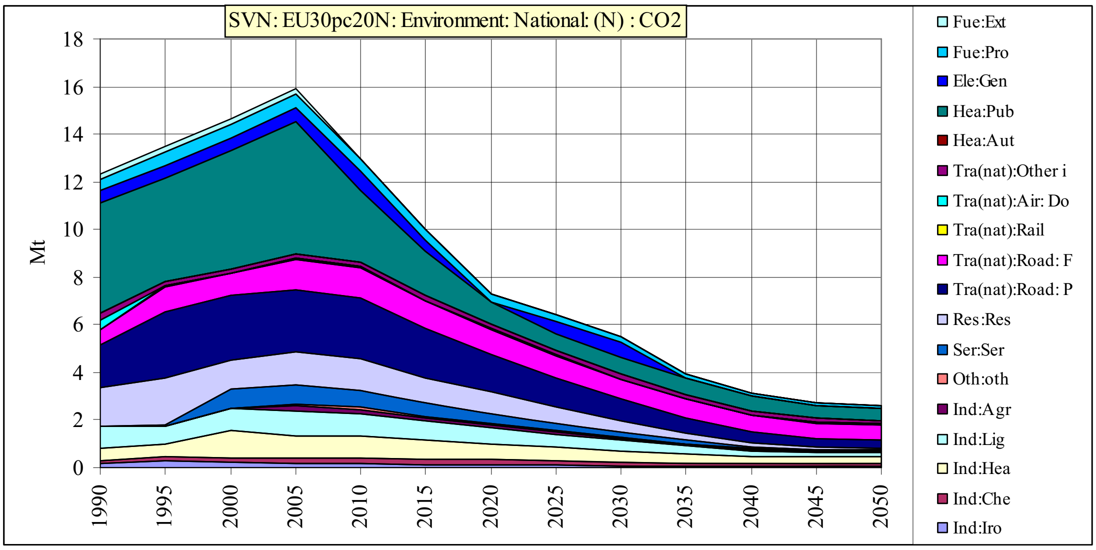
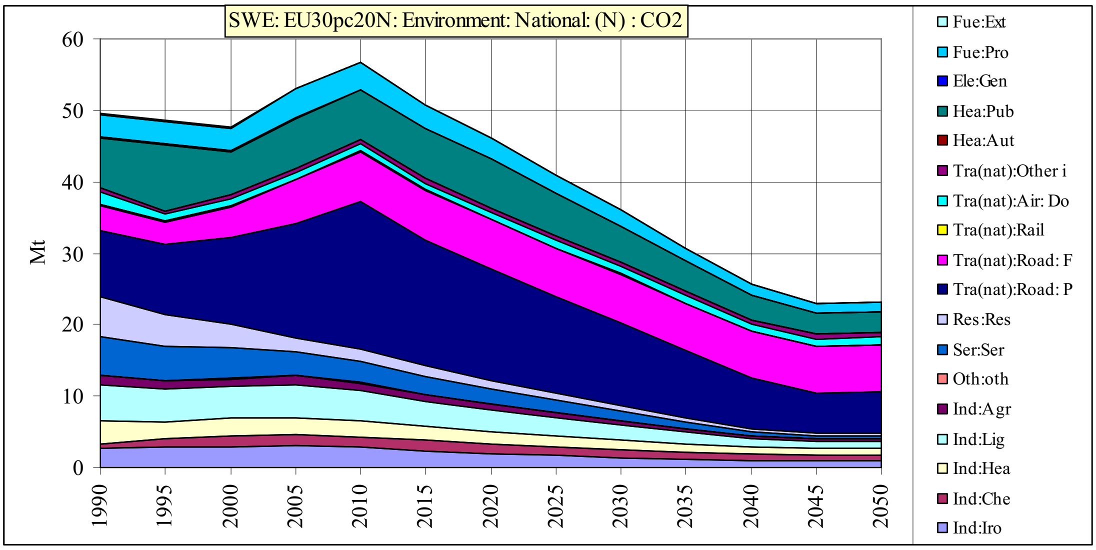
2045
2050
Fue:Ext
Fue:Pro
Ele:Gen
Hea:Pub
Hea:Aut
Tra(nat):Other i
Tra(nat):Air: Do
Tra(nat):Rail
Tra(nat):Road: F
Tra(nat):Road: P
Res:Res
Ser:Ser
Oth:oth
Ind:Agr
Ind:Lig
Ind:Hea
Ind:Che
Ind:Iro





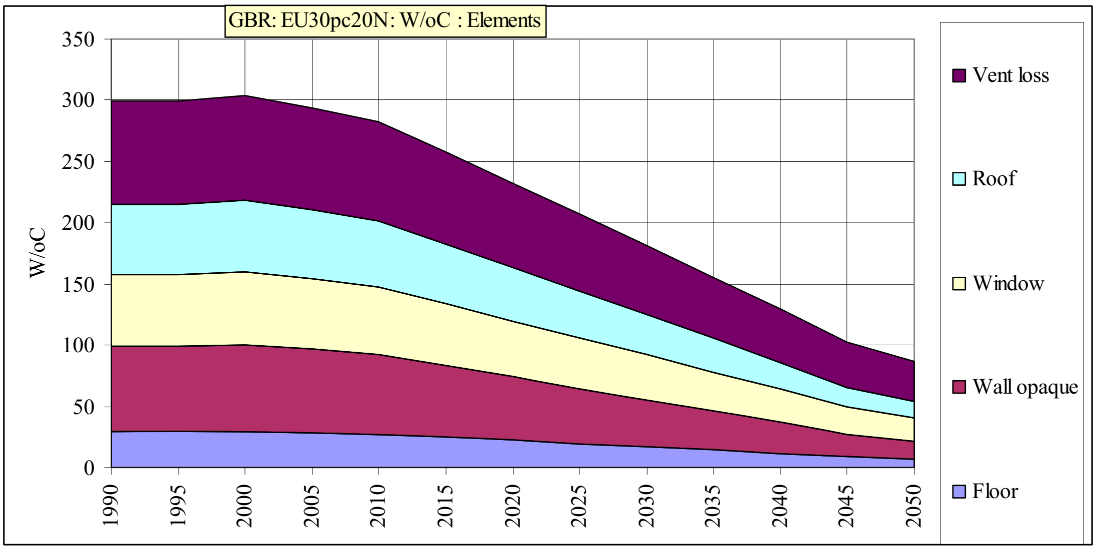
5.3. Sample sectoral results

SEEScen models all sectors for each country which results in a large volume of data. This section gives selected results for certain countries and sectors to illustrate the effects of some of the emission control options.

5.3.1. Residential sector

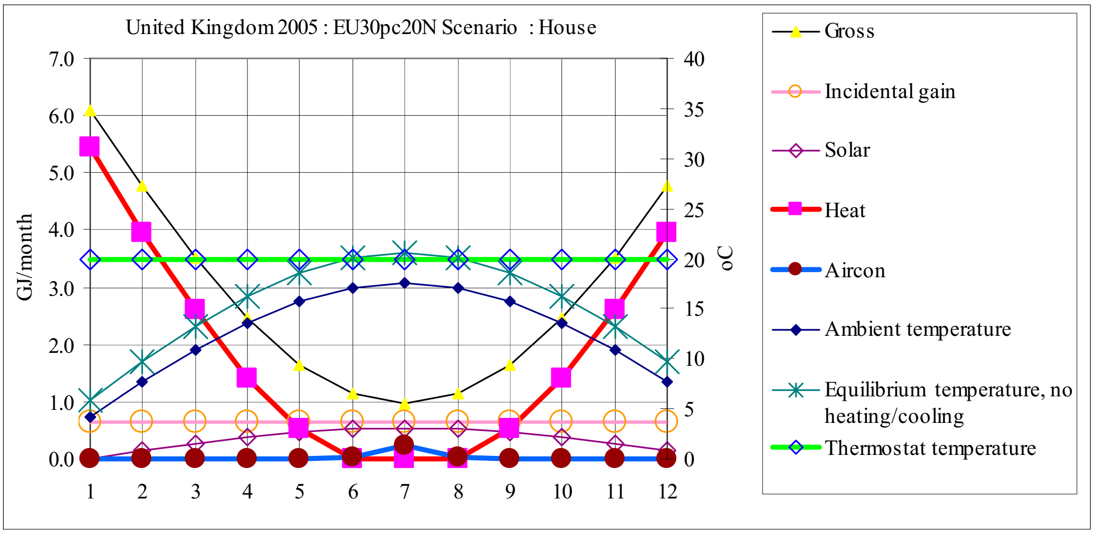
Space heating is a significant energy demand in most of Europe and may be reduced by insulation, better windows and ventilation control. The next Figure shows the evolution of the heat loss elements from an average house. Note that the rate of improvements is such that this assumes the retrofitting of measures to existing dwellings.

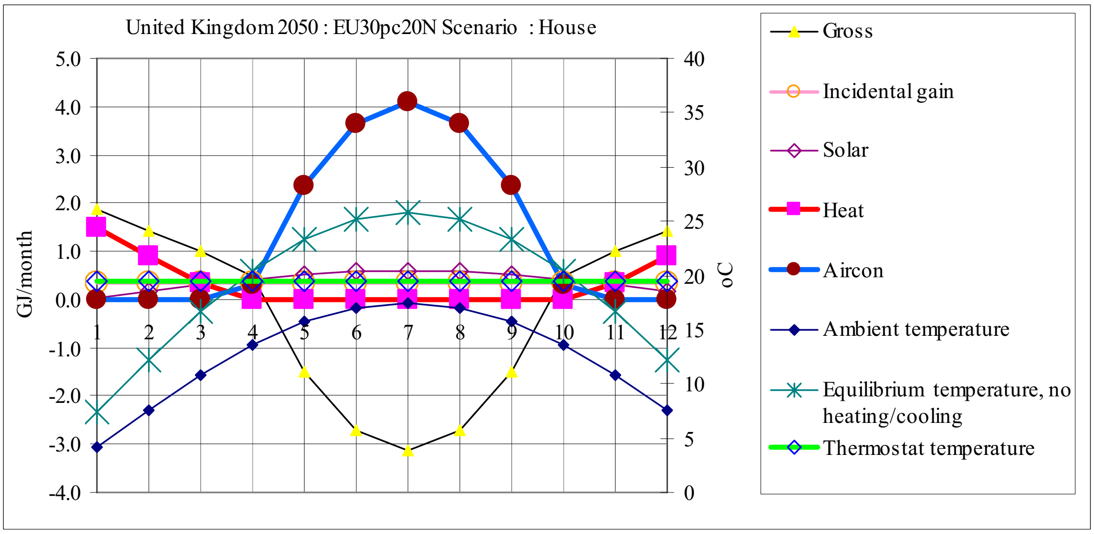
Figure 23 Dwelling heat loss factors: GBR



SEEScen includes a simple model of residential space heating and cooling which accounts for the climate of each country; changes to fabric and ventilation, and heat gains from appliances and passive solar heating are modelled. The following two Figures show the monthly heat and cooling needs for 2005 and 2050 that result after the demand management measures shown in the preceding Figure are implemented. It may be seen that space heat demands are reduced, but that air conditioning demands increase in this simple model because the balance between internal incidental heat gains and heat losses change. If it is assumed that a maximum temperature of 28 C^{o} is allowed and measures to reduce overheating are deployed, then this latter is not as large as shown.

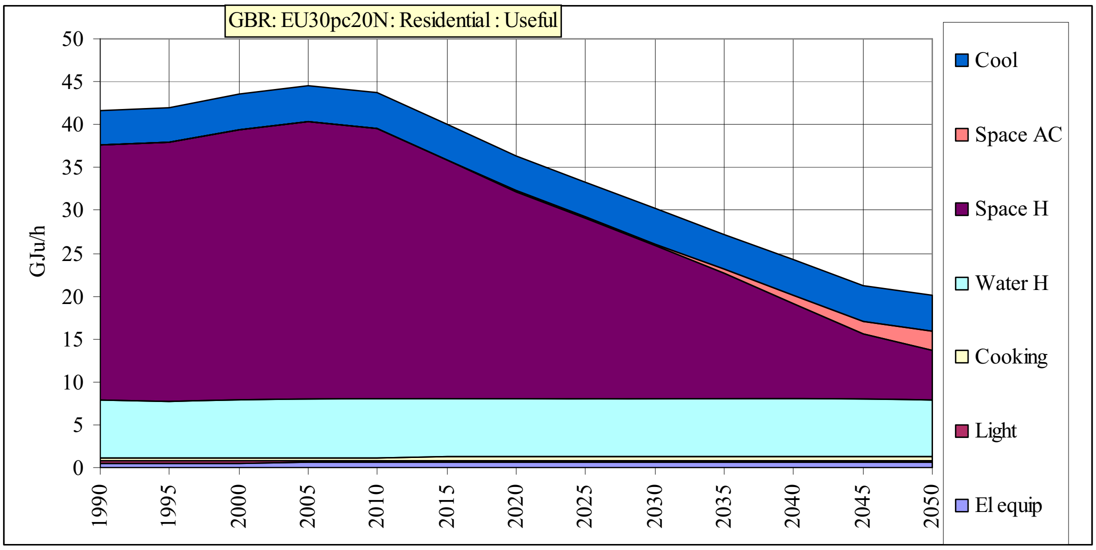
Figure 24 Dwelling seasonal heat and cooling loads: GBR





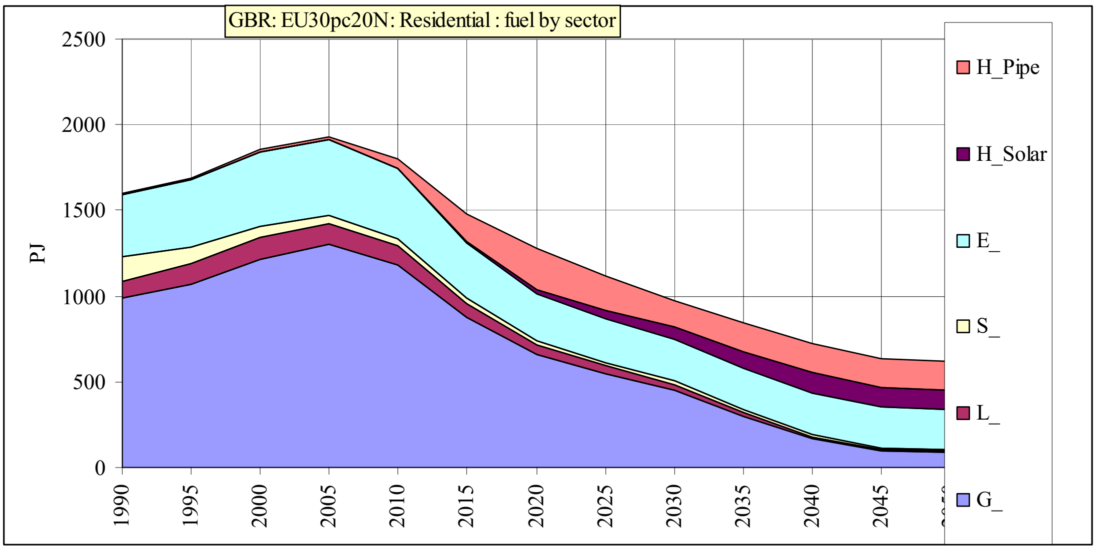
The useful energy demands for the residential sector then evolve as shown in the next Figure. It may be seen how space heating declines and air conditioning increases.

Figure 25 Dwelling useful energy loads: GBR



Solar water heating, district heating and heating with electric heat pumps substantially replace gas and other heating fuels. An increase in the fraction of heating using electricity is balanced by building demand management and the improved efficiency of appliances such as lights, cookers and freezers. This is illustrated in the next Figure.

Figure 26 Residential energy deliveries: GBR



Legend: G_-gas, L_-liquid, S_-solid, E_-electricity, H_Solar-solar heat, H_Pipe-piped district heat

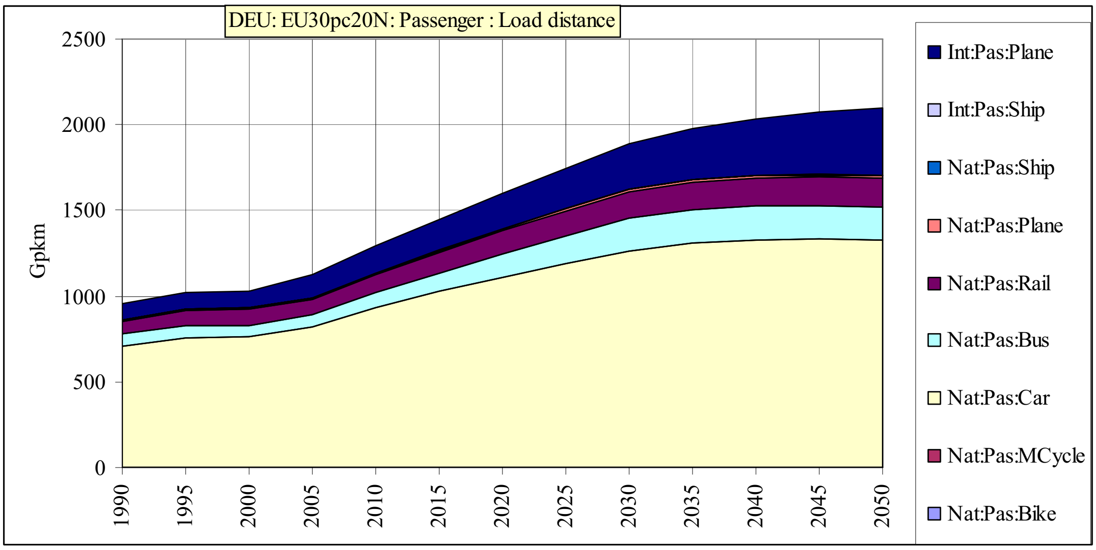
5.3.2. Transport sector

Transport is disaggregated by:

- National (Nat) and International (Int)
- Passenger (Pas) and Freight (Fre)
- Vehicle type: Bike, MotorCycle (MCycle), Car, Bus, Rail, Plane, Ship, Truck, Light Duty Vehicle (LDV) and Pipeline (Pipe)
- Fuel: Gasoline (G), Diesel (D), LPG (LPG), Liquid biofuel; (LB), CNG (CNG), Hydrogen (H2), and Electric (E)

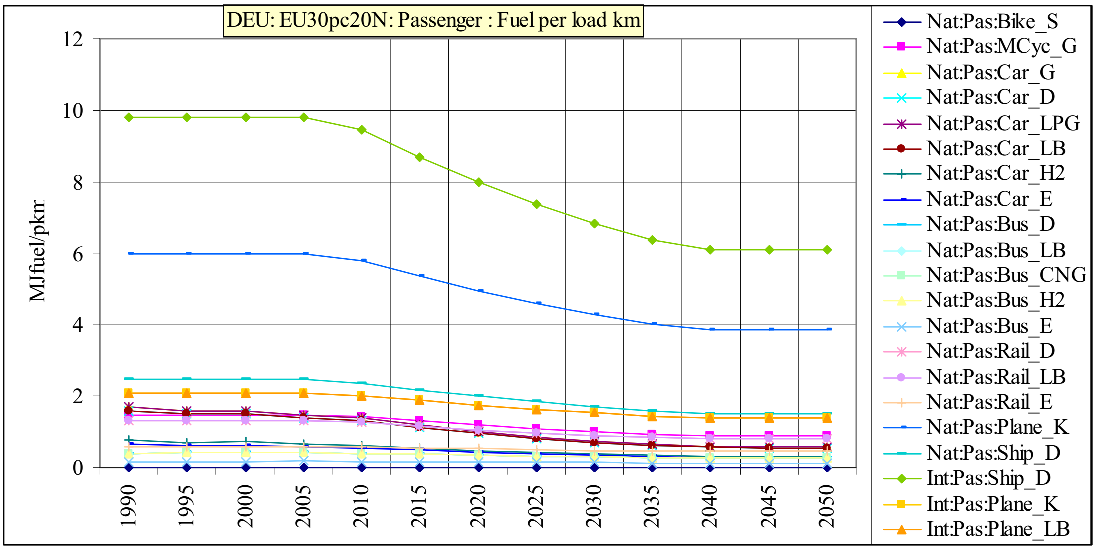
It was noted above that assumptions about basic passenger demand are taken from PRIMES scenarios, but that the modal mix may be altered. The next Figure shows the change in passenger distance (p.km) by mode of transport. This shows a small shift of mode from car to bus and train.

Figure 27 Passenger transport demand – DEU (Germany)



Large reductions in emissions can be made by consumers choosing cars with lower fuel consumption, and by reducing motorway speeds; some details of this are given in Appendix 1. In consequence of technological improvements, downsizing and higher load factors, the fuel per passenger (or tonne) km decreases across the scenario.

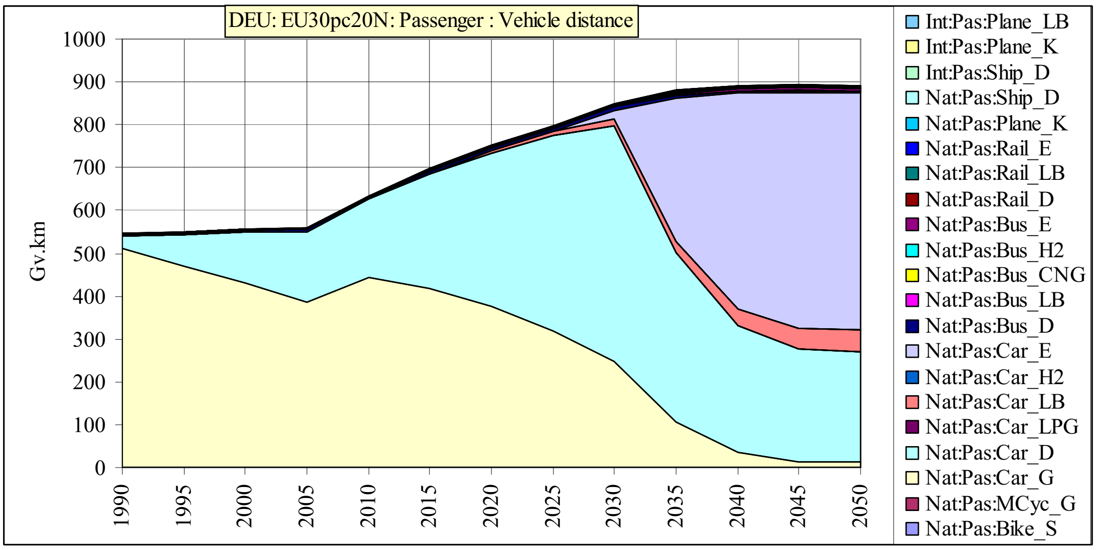
Figure 28 Fuel per load kilometre – DEU (Germany)



See beginning of section for legend explanation

The mix of cars shifts away from gasoline to diesel, and then to electric power and a small amount of biofuels. The next Figure shows vehicle distance by technology and mode; distance is dominated by cars because of the modal mix and because cars carry fewer passengers per vehicle than other modes.

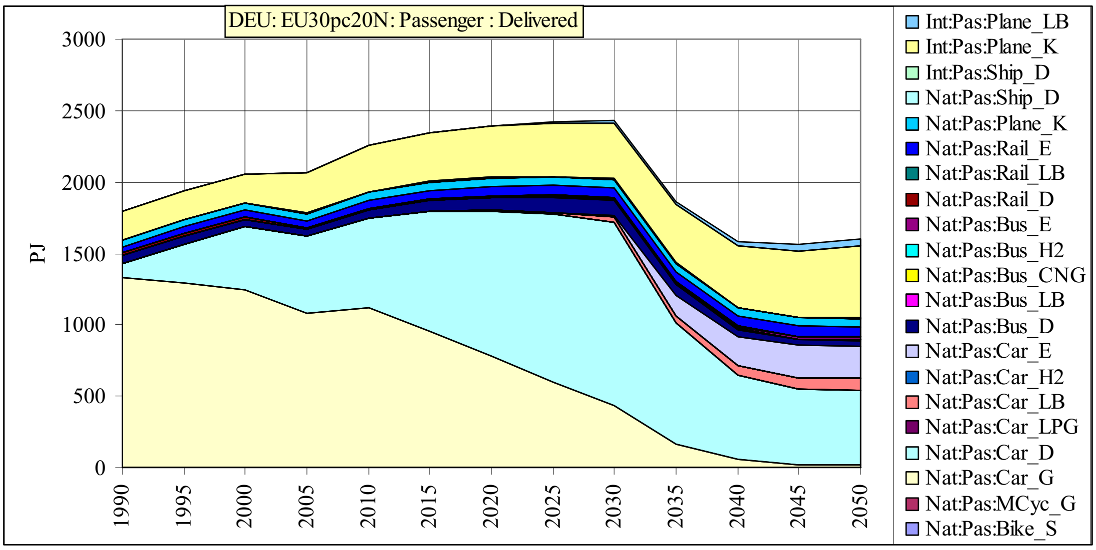
Figure 29 Vehicle distance by technology and mode – DEU (Germany)



See beginning of section for legend explanation. GV.km-billion vehicle km.

Electric vehicles result in lower delivered energy because, in the vehicle, electric power train systems (engine and transmission) are more efficient than combustion or fuel cells. Electric vehicles also reduce emissions at the point of use, thus contributing to urban air quality improvement.

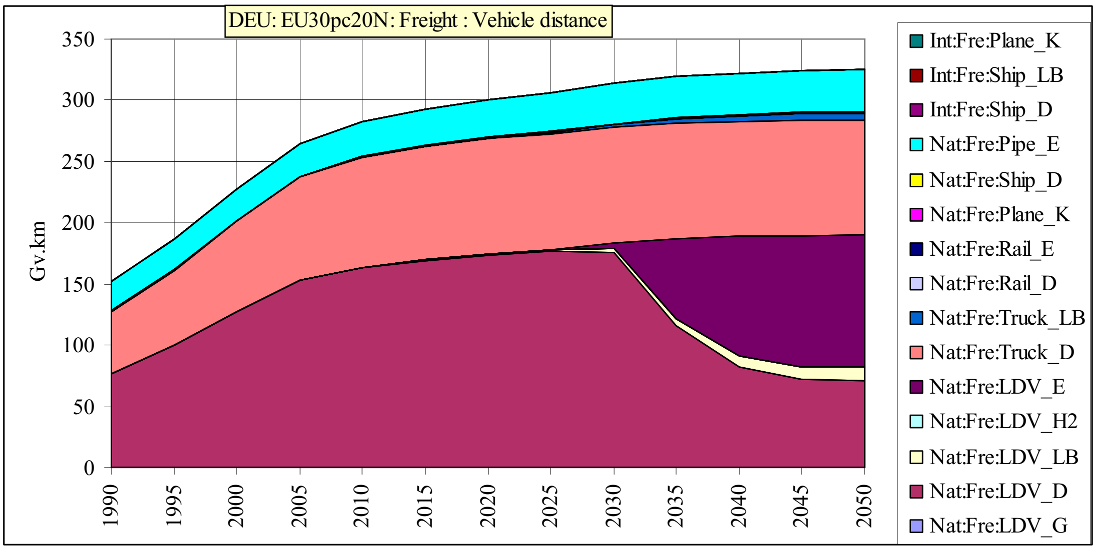
Figure 30 Delivered energy by passenger technology and mode – DEU (Germany)



See beginning of section for legend explanation. PJ-PetaJoules energy

As for passenger cars, electric vehicles become a significant part of the stock of Light Duty Vehicles (LDVs).

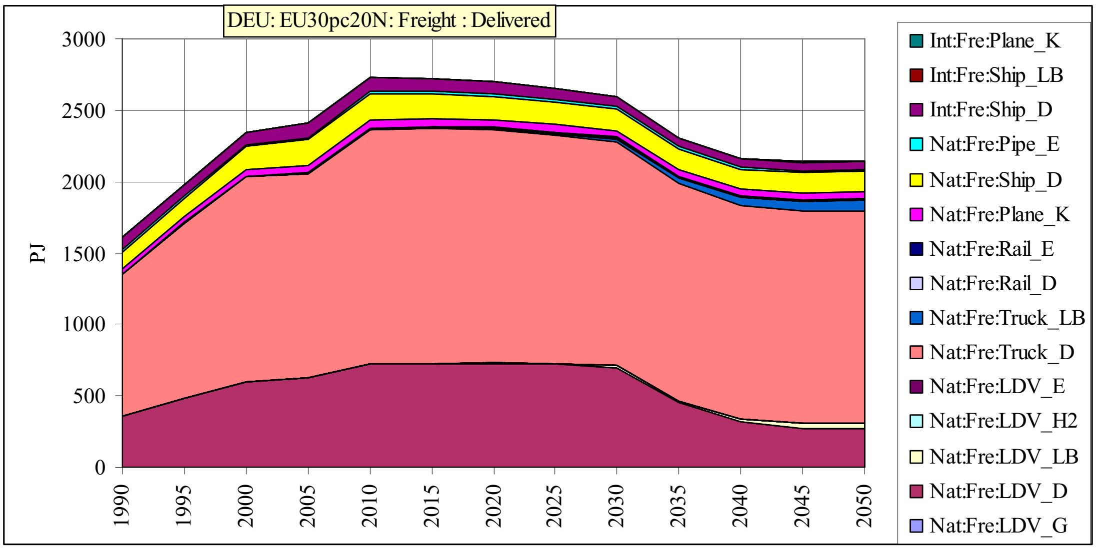
Figure 31 Delivered energy by freight technology and mode – DEU (Germany)



See beginning of section for legend explanation

As for passenger transport, increases in demand are outweighed by improvements in efficiency, operations and modal change.

Figure 32 Delivered energy by freight technology and mode – DEU (Germany)



See beginning of section for legend explanation

5.3.3. Electricity supply

A key and complex sector of the energy economy is electricity supply. SEEScen does not contain a detailed electricity system model: this is required to accurately estimate energy flows and emissions in electricity systems. Barrett (2006) demonstrates that a system with varying demand and a large fraction of generation coming from variable renewable sources is possible for the UK provided there is some storage, fossil back-up generation and some international electricity exchange. This work shows that high penetrations of renewable energy are possible for the UK, even without a large hydro component, but similar analyses are required for each of the EU25 countries, for the EU25 as a whole, and for trade with nearby countries such as Russia.

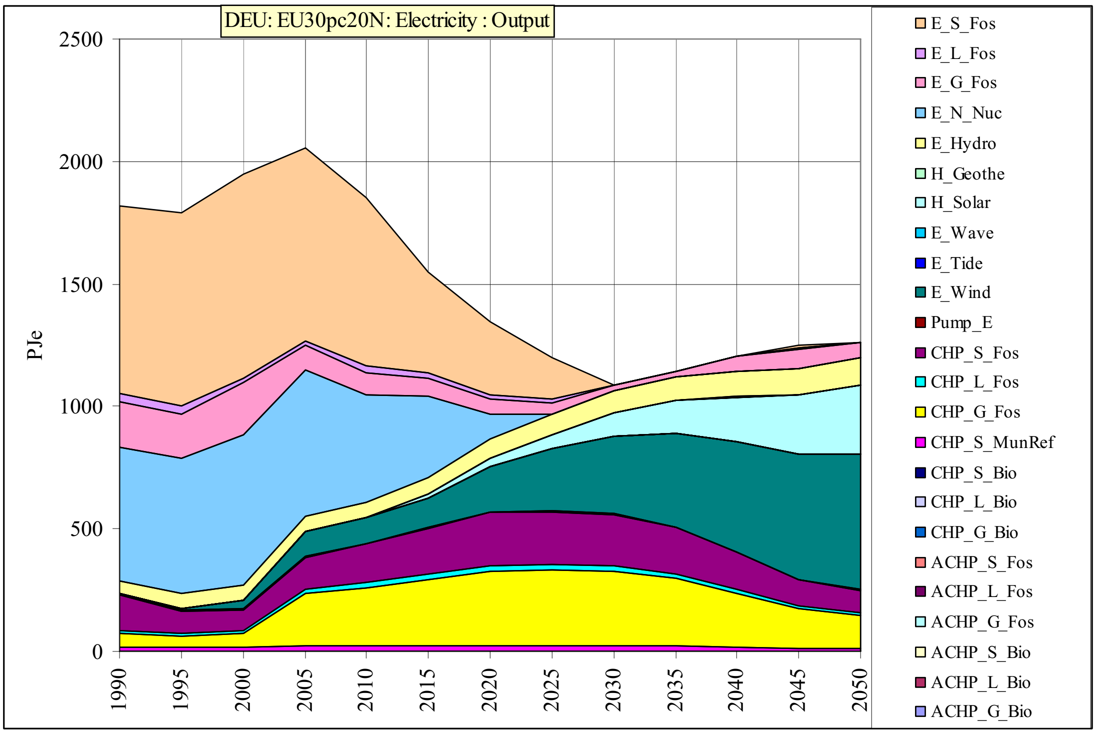
The following Figures show the mix of electricity supply in the EU30pc20 scenario for the six countries emitting the most carbon dioxide. Note that supply does not in general match demand because of trade and in the EU30pc20N scenario there is a net export of electricity from the EU, so supply exceeds demand on average. Also, there are particular problems reconciling heat and electricity production in historic IEA energy statistics.

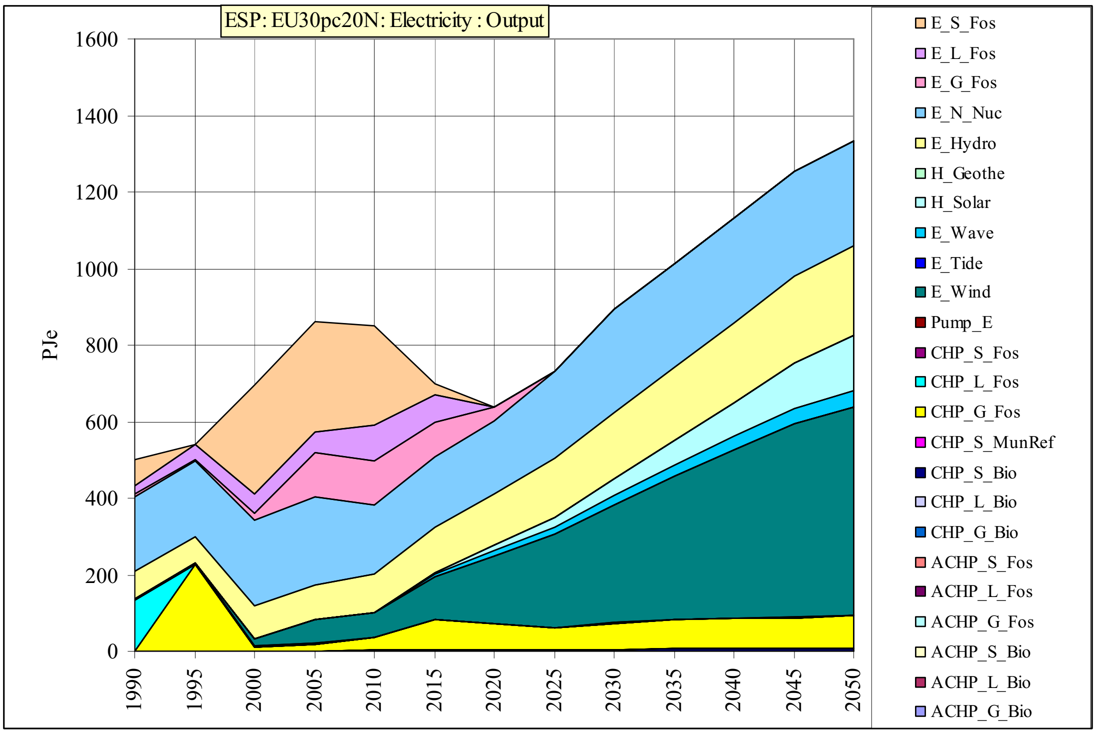
The general trends are the reduction in the use of coal as a generating fuel, and the maintenance or increase in a mixture of renewables and CHP generation. Note, however, that fossil based CHP can increase to make efficient use of gas for heating, and then decline as renewable capacity increases and gas depletes.

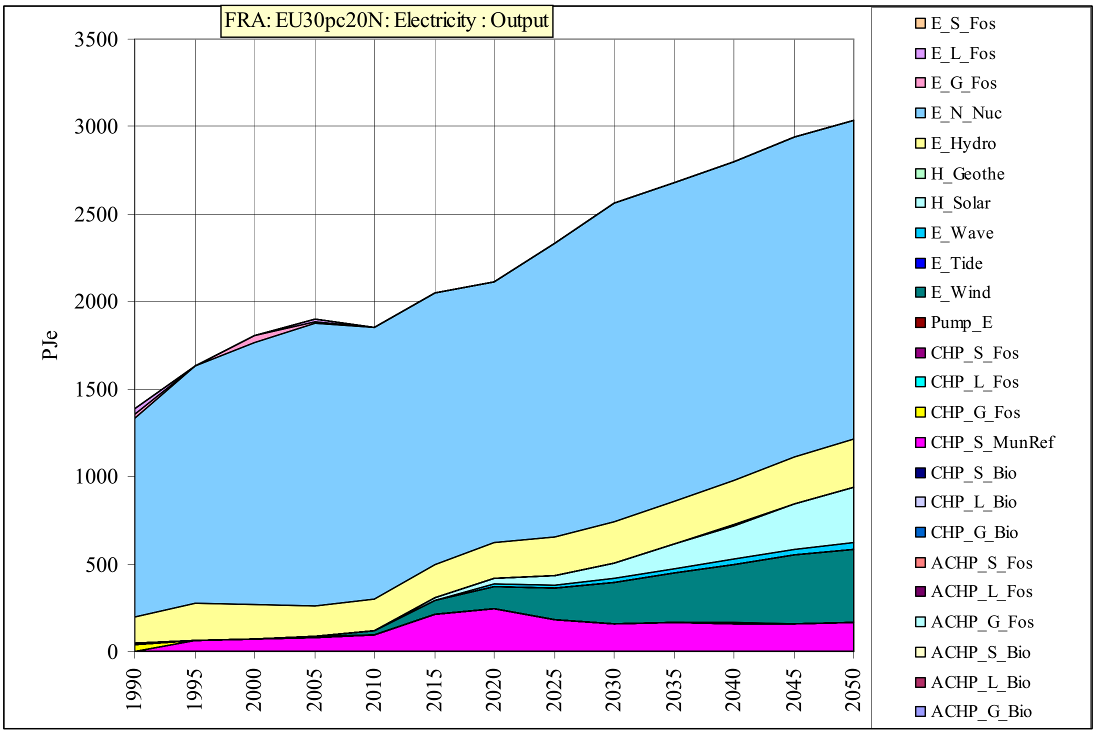
The legend for these graphs is as follows:

- Fuels: S/L/G_Fos solid/liquid/gas fossil. Nuc-nuclear, Hydro, hydro, Geothe- geothermal, S_MunRef-solid municipal refuse, S/L/G_bio-solid/liquid/gas biomass.
- Technology: E_-electricity only, H_-from geothermal;/solar heat. CHP-CHP with district heating, ACHP-auto (private) CHP without district heating.

Figure 33 Electricity generation of selected countries




ESP: EU30pc20N: Electricity : Output
PJe
1600
1400
1200
1000
800
600
400
200
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
E_S_Fos
E_L_Fos
E_G_Fos
E_N_Nuc
E_Hydro
H_Geothe
H_Solar
E_Wave
E_Tide
E_Wind
Pump_E
CHP_S_Fos
CHP_L_Fos
CHP_G_Fos
CHP_S_MunRef
CHP_S_Bio
CHP_L_Bio
CHP_G_Bio
ACHP_S_Fos
ACHP_L_Fos
ACHP_G_Fos
ACHP_S_Bio
ACHP_L_Bio
ACHP_G_Bio


FRA: EU30pc20N: Electricity : Output
PJe
3500
3000
2500
2000
1500
1000
500
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
E_S_Fos
E_L_Fos
E_G_Fos
E_N_Nuc
E_Hydro
H_Geothe
H_Solar
E_Wave
E_Tide
E_Wind
Pump_E
CHP_S_Fos
CHP_L_Fos
CHP_G_Fos
CHP_S_MunRef
CHP_S_Bio
CHP_L_Bio
CHP_G_Bio
ACHP_S_Fos
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ACHP_G_Fos
ACHP_S_Bio
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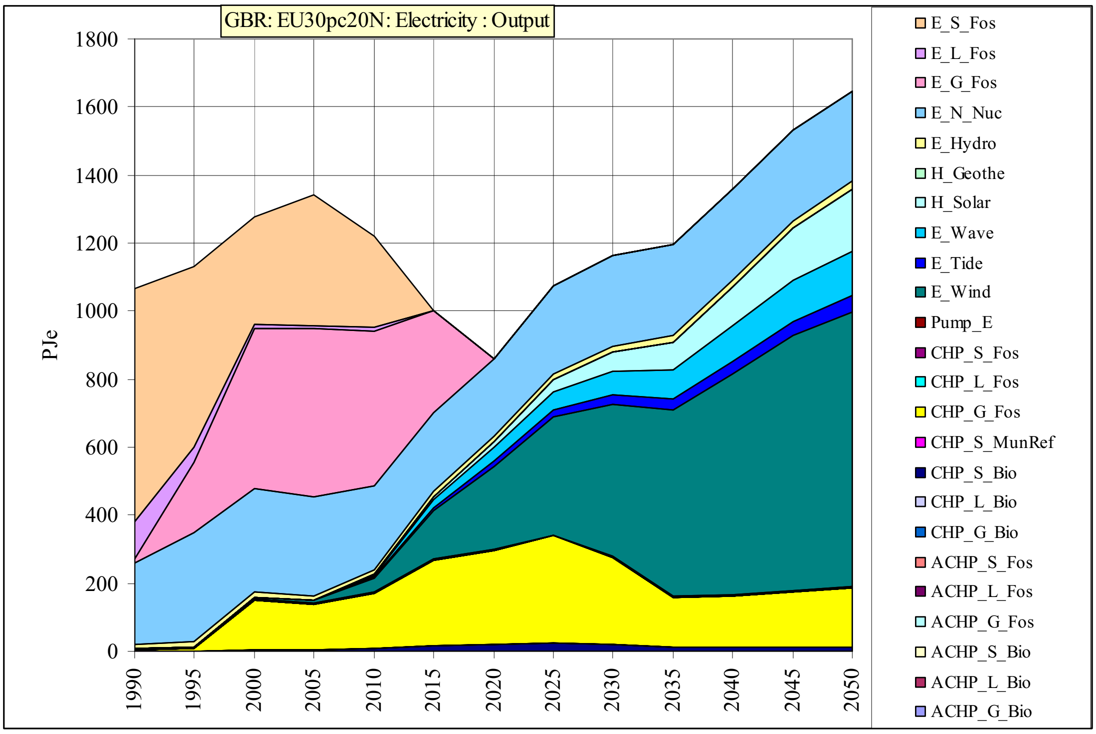


5.4. Variant scenarios

The next Figure shows EU25 carbon emission for the variant scenarios, described in Table 4, in which NEOP measures are implemented to the different degrees. These variants underline the importance of early introduction and the rates of change of measures, because emissions are still declining after 2020. The variants also show that reductions larger than 30% are possible. The last scenario, TecBehNN, shows what might be accomplished with high application of all NEOP measures, but no new nuclear power. This should not be taken as the maximum reduction in CO_2 emission. It is possible to eliminate CO_2 emission altogether, but over this timescale, this would probably not be justifiable on environmental grounds, or desirable from a social or economic perspective.
It is also emphasised that technological development may radically change the longer term picture — for example, the development of cheap solar photovoltaic devices, electricity storage and transmission would radically transform energy and environment policy mixes.

Figure 34 EU25 countries carbon emission: EU40pc20N scenario

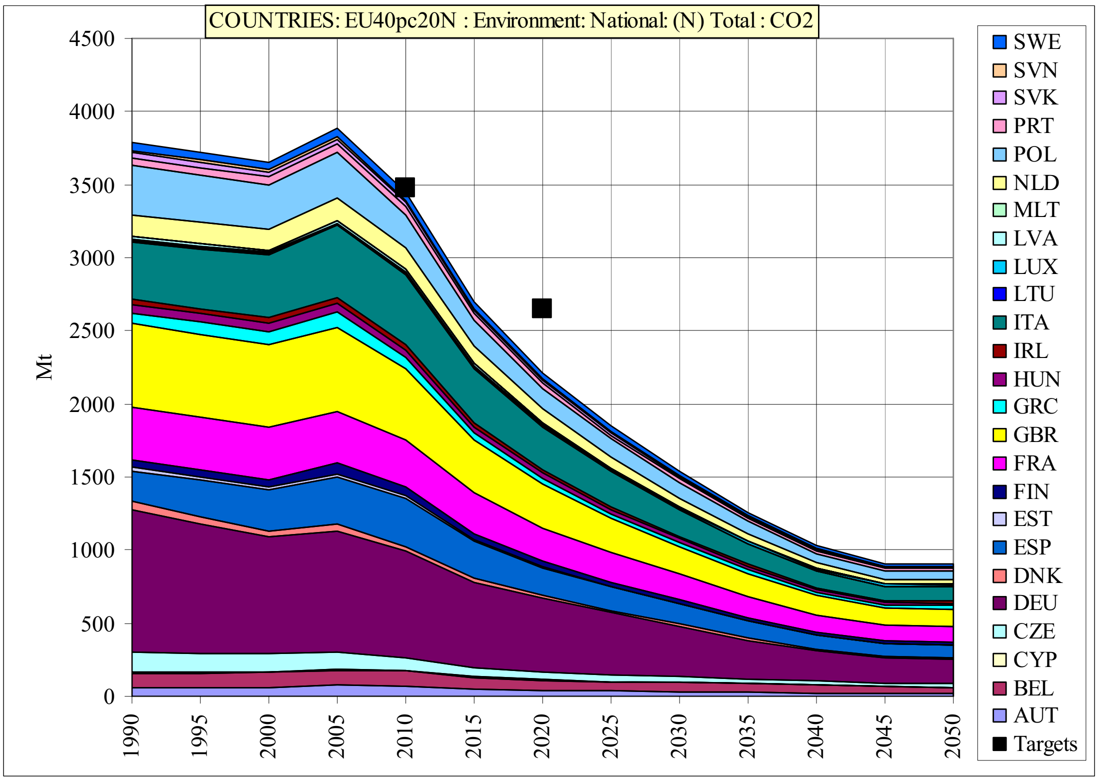


Figure 35 EU25 countries carbon emission: EU30pc20NN scenario

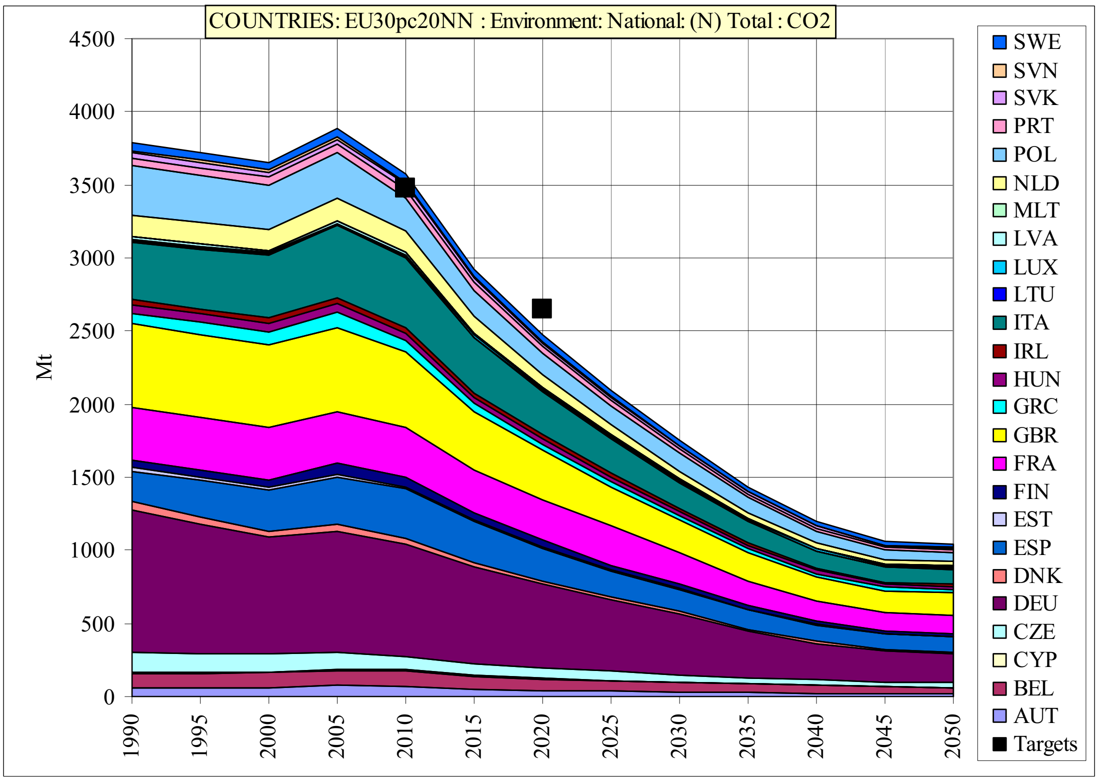


Figure 36 EU25 countries carbon emission: BehNN scenario

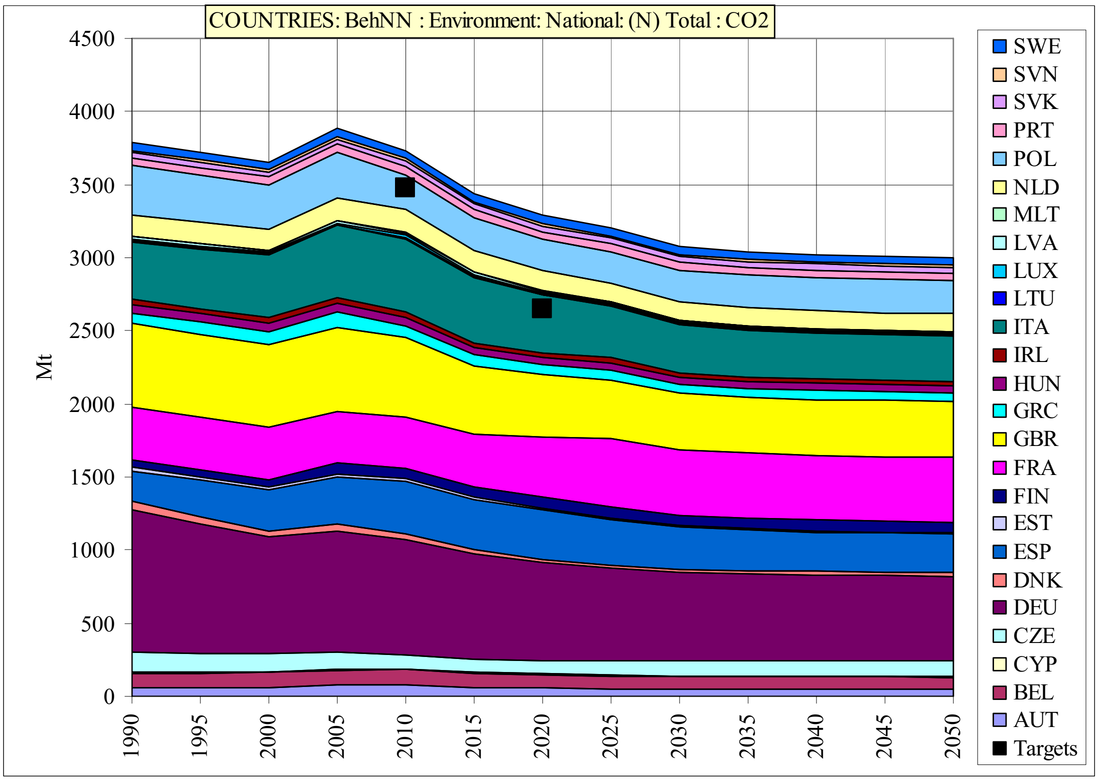


Figure 37 EU25 countries carbon emission: TecNN scenario

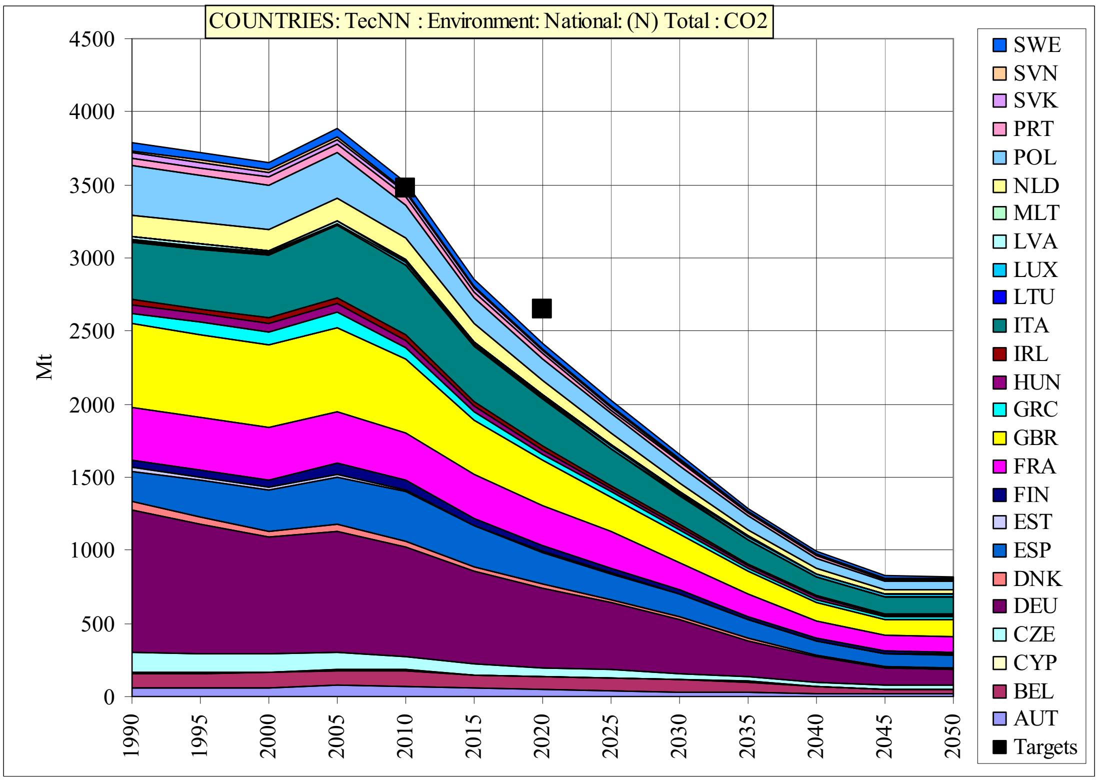
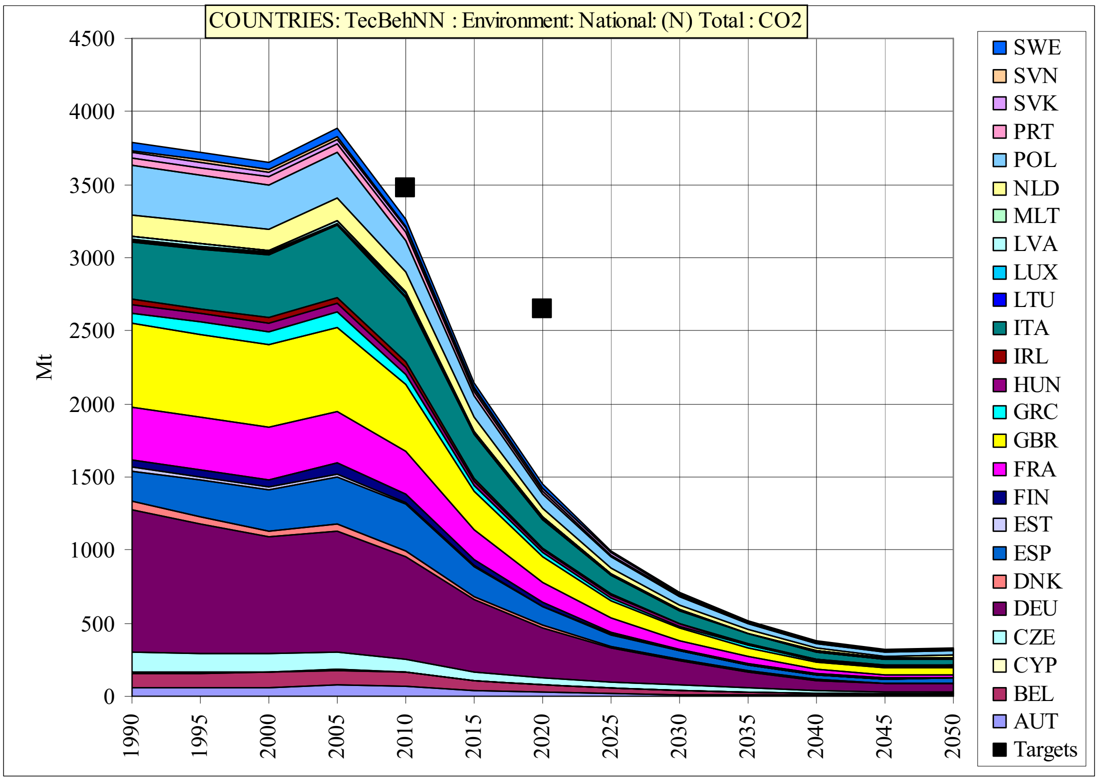


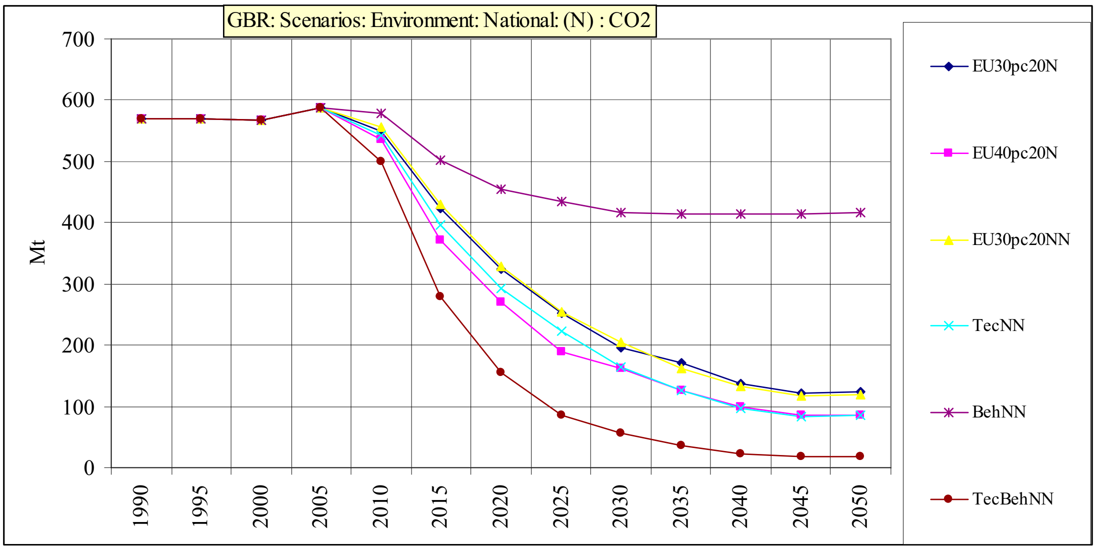
Figure 38 EU25 countries carbon emission: TecBehNN scenario



The next Figure shows UK CO_2 emissions for the six scenarios. This illustrates:

- how purely behavioural changes rapidly reduce emissions by about 30%, but not by 2020.
- how purely technological options reduce emissions further, but take longer to penetrate.

Figure 39 Country CO_2 emissions by scenario: UK



6. Economics

SEEScen calculates the energy service system costs. These costs are direct market costs, exclusive of tax and subsidy. No welfare costs are included. This is particularly problematic when costing options which assume behavioural change. For example: a small car may produce half as much CO_2 as a large car and cost half as much, giving a large negative direct cost for CO_2 abatement. Yet plainly there are features of large cars which are of value to consumers and so the cost to them is not negative.

The costs of demand technologies such as insulation and ventilation control, and end use and supply energy conversion technologies are included. Energy storage and transmission systems are not costed in detail.

For these technologies SEEScen calculates:

- The annuitised capital costs. These are calculated over the assumed 'normal ' technical lifetimes of the technologies (see Table 7). Currently in the scenarios there is no implicit assumed premature replacement of technologies.
- Annual operation and maintenance costs;
- Fuel costs.

These elements may be reported separately, or summed to give an estimate of the total cost of the energy service supply system. The differential cost of packages of options in scenarios is found by calculating the total costs of each scenario and finding the difference between them.

Certain technologies are not included, for example, transport infrastructure (road, rail, etc.) as implicit in traffic forecasts and modal split. The issue arises here as to how to assign the costs of options such as modal change (e.g. road to rail) – is it an energy service cost, or a transport cost?

In general, low carbon measures will affect total costs in these ways:

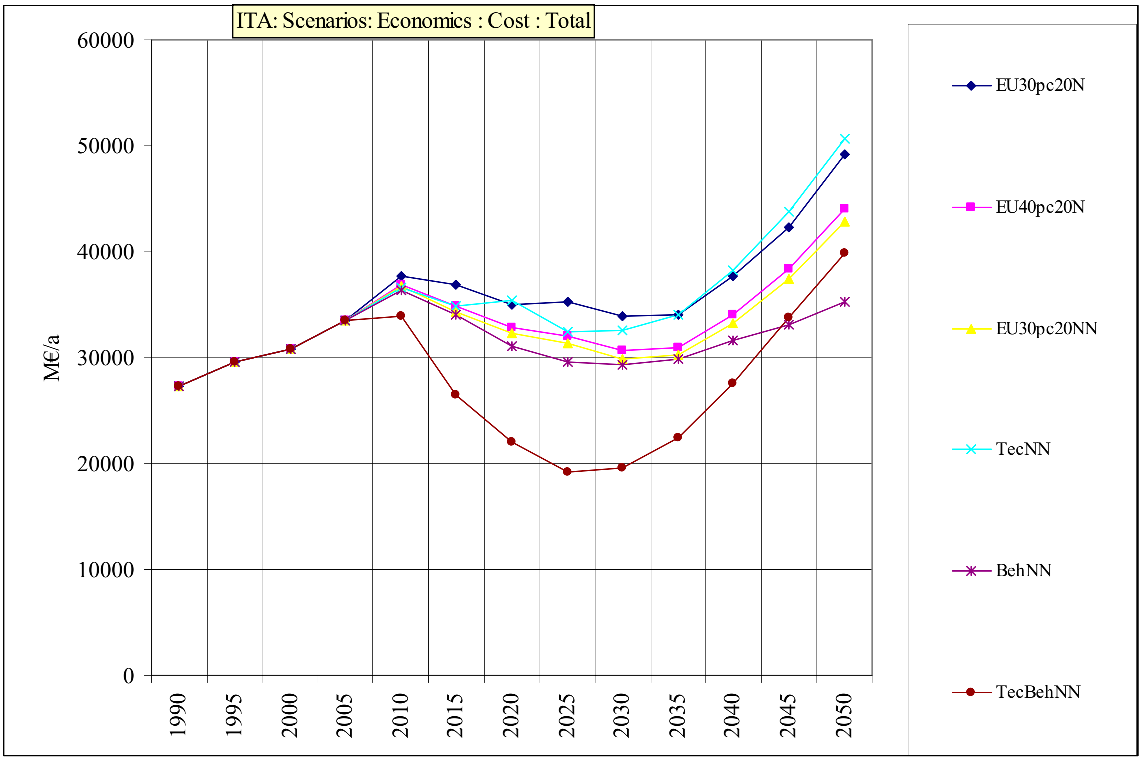
- More will be spent on demand management and renewable capital costs
- Less will be spent on fuel because of lower fuel consumption and lower fuel prices

It is possible that some low carbon scenarios will cost less than high carbon scenarios; and manifest more economic stability because of less dependence on unpredictable escalations and fluctuations in fossil fuel prices. A key issue is how international fuel prices will vary according to the fuel consumption of Europe and other regions. It is to be expected that in the high carbon scenarios, fuel prices will be higher than in the low carbon scenarios.

The next Figure gives sample total direct (NEOP) energy costs for Italy across the six scenarios. These are only illustrative at this stage because the capital and running costs of technologies require review, as does the linkage between fossil fuel consumption and price.

Comparing total costs with the End-of-Pipe emission control costs given by GAINS, it is clear that the total annual costs of an energy system (demand, supply) are likely to be an order of magnitude larger than the total costs of End-of-Pipe emission control. This is not surprising considering the small fraction of the total capital and running costs of a power station that a flue gas desulphurisation plant comprises, or of a car that a catalyst and particle trap represents.

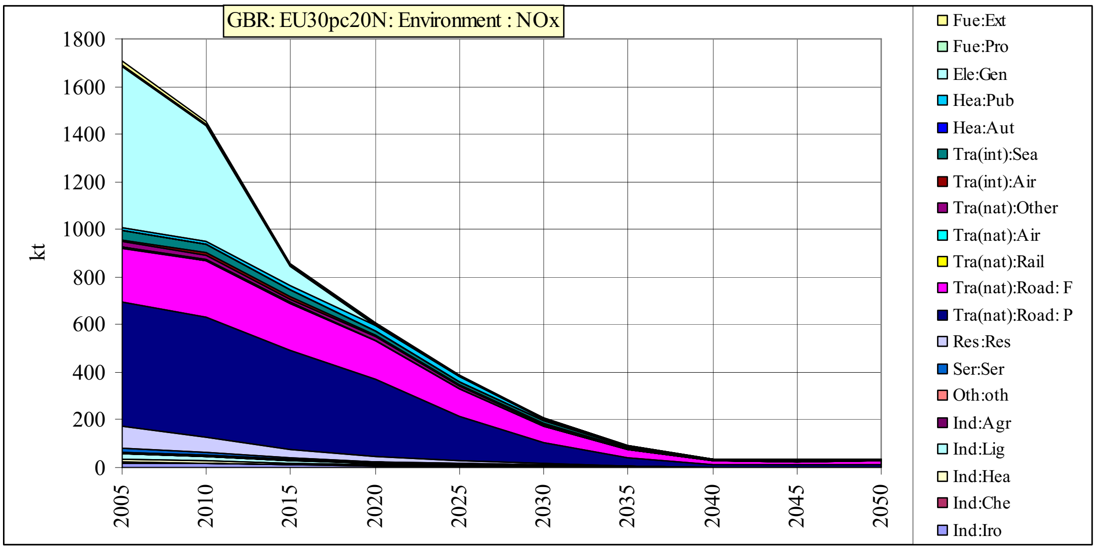
Figure 40 Total costs of energy scenario: Italy



6.1. Emissions in the longer term

SEEScen calculates the emissions of SO_2, NO_x and CO, but the emission factors are not validated yet. The next Figure illustrates how the emission of NO_x continues to fall after 2030 as fossil fuel consumption is further reduced, and emission control technologies are further applied. (See Table 8 for legend.)

Figure 41 Illustrative NO_x emissions: UK



6.2. Emissions in space and time

SEEScen does not disaggregate energy use and emissions spatially, or model flows on a time period less than a year. However, the changes that arise in the scenarios will alter the pattern of emissions spatially and temporally. Some general remarks are made about these patterns which may apply generally, but not in every country and urban area. Detailed spatial and dynamic modelling is needed to quantify these changes in patterns.

These are general observations about spatial distributions:

- Urban low level (height) traffic emissions will diminish because of reduced traffic, modal shift and the increasing fraction of electric vehicles.
- Demand management, energy efficiency and a switch to renewables will increase electric heating with heat pumps, and reduce fossil fuel use and emissions in buildings.
- An increase in CHP will occur, but this will largely replace individual fossil fuelled boilers. CHP emissions will be less than from the aggregate of individual installations because of greater efficiency and better emission control, and will occur at greater height because of stack height.
- Arguably, biomass will typically be used in CHP plants as near to biomass sources as possible as this maximises efficiency. In most countries, the main biomass source is agricultural, and so biomass CHP plants would be sited in areas with low population density, or at urban peripheries.
- High level (height) emissions from remote power plants will decline because of the shift to zero carbon generation and increasingly stringent emission controls.

These changes will lead to lower urban emissions with concomitant implications for urban air quality.

Concerning temporal patterns of emission, these observations are made:
- Demand. Management for space heating (e.g. insulation) will reduce the winter:summer heat demand ratio. If building design is effective, overheating and air conditioning loads can also be reduced. Demand management should reduce climate induced variation for heating and cooling across the day and the seasons.
- Supply. Renewable energy will reduce annual emissions from fossil supply, but fluctuations in fossil supply will be greater as it will be used most when renewable energy supply is low – for example, at times of low wind fossil plant may be used to replace the output from wind turbines. It may be that peak emissions are similar to those from a high fossil supply system, even though annual emissions are a small fraction.

The net result of these factors will vary according to demand and supply mix, and climate.

6.3. International aspects

6.3.1. Energy security

Energy supply security is a growing concern: EU25 gas and petroleum reserves and production will decrease rapidly over the coming decades. At the same time, demand for these fuels is growing rapidly in large countries such as China and India. Not only does this jeopardise physical supply security, it also increasingly exposes the EU to fluctuating and increasing fuel prices, thereby damaging economic stability. Furthermore, it weakens the EU position in the international political system.

The European Commission issued a Green Paper, *A European Strategy for Sustainable, Competitive and Secure Energy (CEC, 2006b) outlining the issue.*

> *Europe's future depends on a secure, affordable and ecologically sustainable energy supply. It is no longer adequate to assure the simple physical availability of energy sources. Supply policy needs to consider the immediate and longer-term availability of energy products at a price which is affordable to all consumers (domestic and industrial), while respecting environmental requirements and the needs for sustainability. It also needs to take into account trends in demand.*
>
> *Under current patterns of energy production and energy use, the European Union is consuming limited reserves at rate which compromises the availability of energy to future generations and threatens the local and global environment. This document analyses the background to this assertion and anticipates the Commission's Green Paper on Energy Supply Security.*

> *For the European Union (EU), energy supply has an internal dimension and an external dimension. Internally, Europe needs to balance supply and demand, while respecting environmental, consumer, safety, political and economic demands. Externally, adequate and suitable supplies must be available to fill the gap between domestic production and domestic needs. The objective of independence from external energy suppliers has been replaced by the objective of managing external dependence.*

The scenarios developed in this work address these concerns by reducing fossil fuel use and increasing the use of indigenous renewable resources. This is shown by consideration of energy trade in the EU30pc20N scenario.

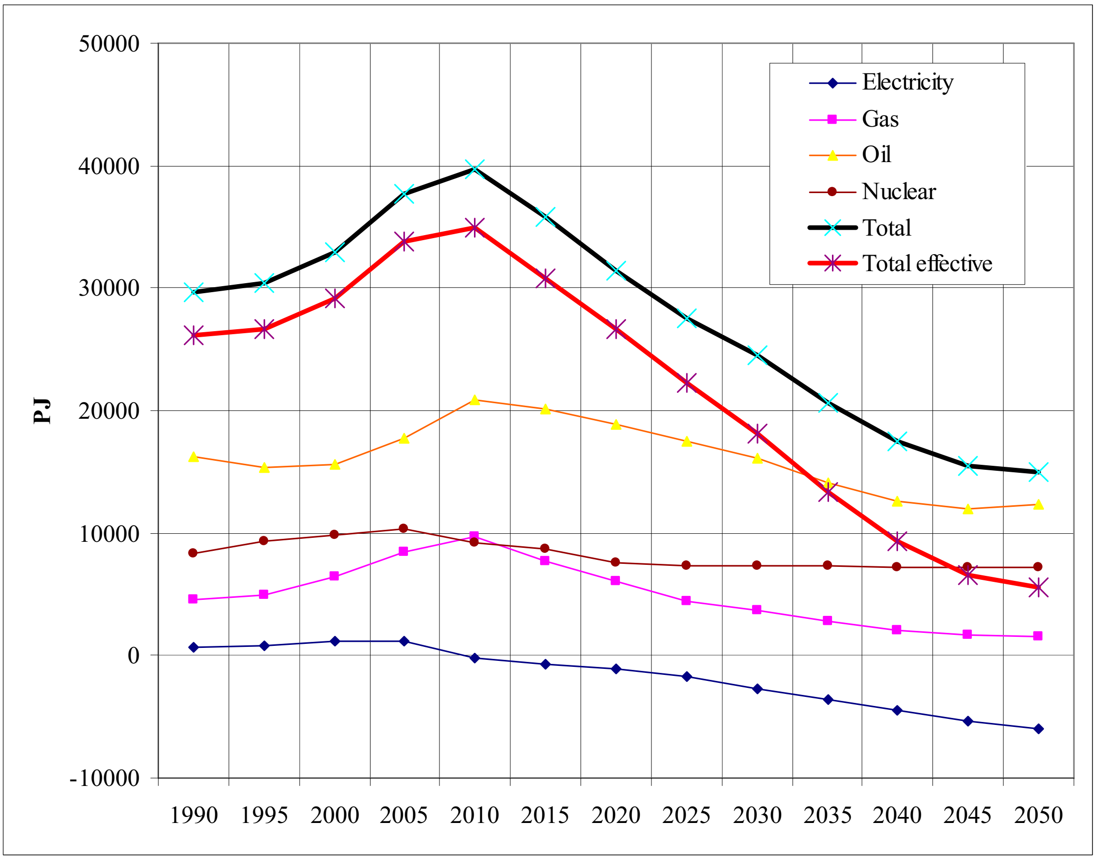
Coal trade is not presented here because global and EU25 coal reserves are sufficient for well beyond 2050 should they be required. Of the fossil fuels, coal has the highest carbon content: energy content ratios and its use is minimised in low carbon policies. Coal trade is mostly determined by cost and quality.

Nuclear energy trade is included as a reminder that this is an import of a finite fuel into the EU25. However, it should be noted that the practical definition of the energy content of nuclear fuels is defined by convention in energy statistics.

The next Figure shows the net trade of gas, oil, nuclear energy and electricity across the EU25's borders in the EU30pc20N scenario. This shows that after 2010, despite declining indigenous EU25 production, the imports of gas and oil decline for some 35 years as the efficiency and renewable measures take effect. Thereafter, imports start to rise again. In contrast, the EU25 becomes a net exporter of electricity.

Summing across all fuels and electricity, total net energy imports decline by about 60% over the period 2005 to 2050. However, electricity is generally 'more useful' than coal as 1 GJ of electricity will typically displace some 3 GJ of coal, which is mostly used to generate electricity at 35% efficiency. If electrical energy is counted as twice the effective energy of gas or oil, as it can be used more efficiently in motors, heat pumps, etc., and four times as effective as nuclear fuel (essentially a heat producer), then total effective energy imports decline by about 85%.

Figure 42 EU25 energy trade: EU30pc20N



Aggregating across all fuels and end use sectors can conceal particular problems with certain fuels and uses which are difficult to substitute. In particular, the continued need to import large volumes of oil arises because of the difficulty in replacing liquid fossil fuels for transport with renewable energy. The question arises whether electricity might further substitute for oil via electric vehicles and rail transport. A further possibility is to synthesise transport fuels from electricity (e.g. hydrogen) or biomass (liquid chemical fuels). The problem is that the overall efficiency of production and use of such synthetic fuels is very low. This signals perhaps the most urgent need for technological development, the reduction in use of fossil transport fuels, and their replacement, especially for aircraft, with renewable fuels.

This trade picture illustrates the importance of minimising delivered fuel requirements through demand management and energy efficiency at the same time as switching to renewable energy. The reduced import of fuels improves security, as it will take place in a context of the global depletion of finite fossil and nuclear fuels.

Plainly, in the scenarios with greater reduction in fossil energy use and CO_2 emissions, fossil fuel imports are further reduced, and energy security thereby enhanced.

This issue also emphasises the need to take a larger Eurasian and global perspective in modelling and analysis. It may be that it is globally optimal for the EU25 to export electricity because of the large wind and wave resource of Western Europe and to import other fuels.

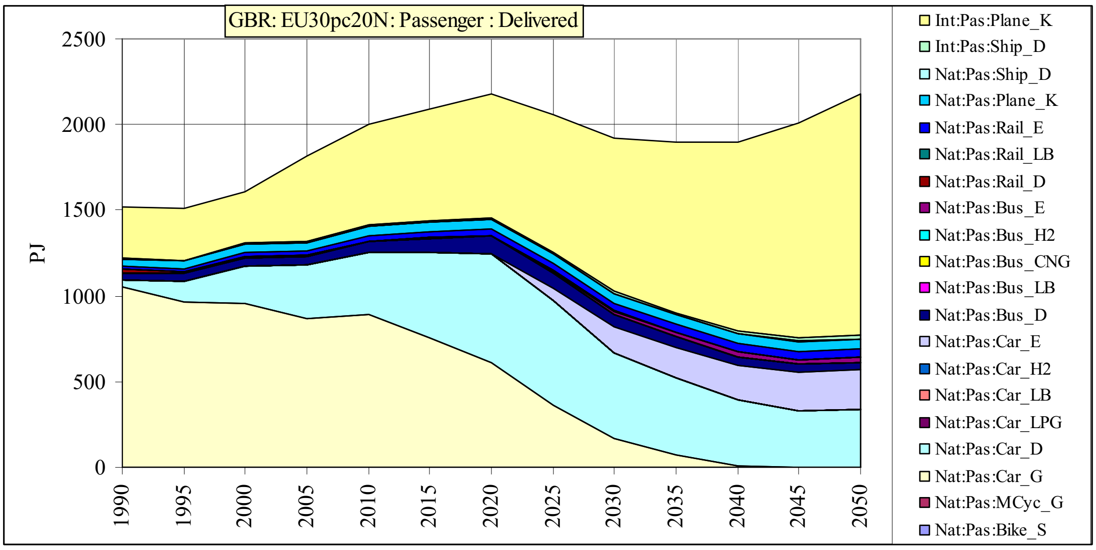
6.3.2. International aviation and shipping

The emissions from international aviation and shipping are excluded from the reduction targets used in this study as they are excluded from international protocols. International aviation and shipping are the most difficult sectors for the future because:

- There are no near physical limits to the space for traffic, unlike for road transport. Aviation is predominantly for leisure and is only limited by wealth and desire. Shipping is driven by burgeoning international trade. For these reasons, there is no near saturation for demand in view.
- Improving fuel efficiency has always been a significant objective for international transport for commercial and other reasons, such as aircraft range, and so future efficiency gains are limited.
- Most international transport uses liquid fossil fuel, the most difficult to replace.

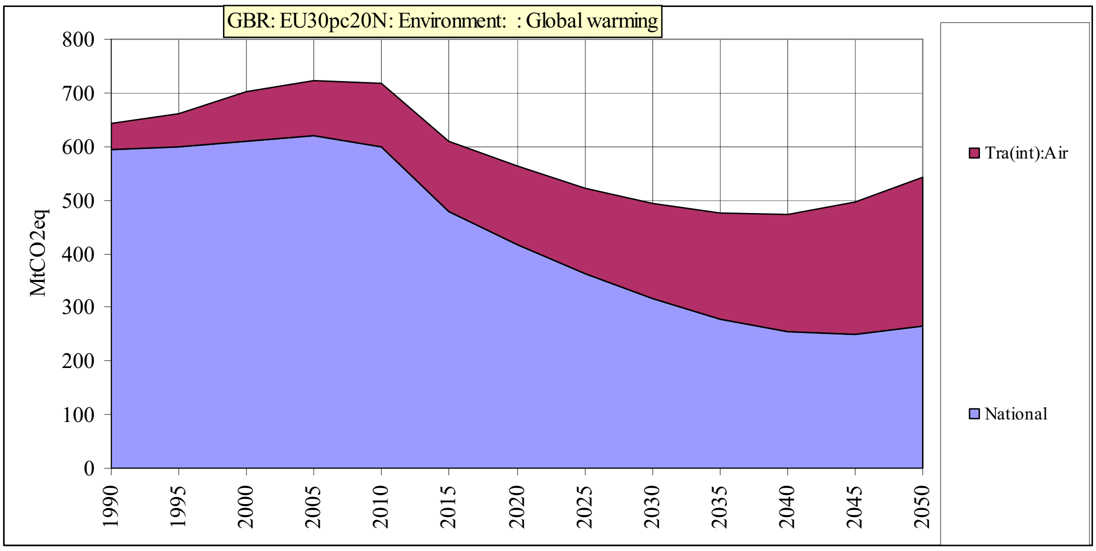
The passenger transport fuel use scenario for the UK is shown in the next Figure; note that the UK is a large exporter of aviation services, so aviation is more significant proportionately than in most countries. It may be seen that aviation kerosene becomes the major fuel consumer and CO_2 emitter for passenger transport.

Figure 43 UK passenger transport fuel use including aviation



The high altitude effects of aviation emissions are such that global warming due to aviation is roughly three times that due to CO_2 alone. The next Figure shows total UK CO_2 equivalent emissions from energy consumption for accounting for this, showing aviation to constitute more than 50% by 2050. 'National' includes all transport emissions apart from those in international space. 'Tra(Int)Air' refers to all international air transport where the fuel is loaded in the UK.

Figure 44 UK surface CO_2 emission and aviation CO_2 equivalent



Patently, international transport has to be included in emission targets designed to combat global warming. Some of the technical, regulatory and fiscal options for controlling aviation emissions have been explored by Barrett (Barrett, 1994; Barrett & Fergusson, 1994; Barrett, 1996).

7. Applying Energy Scenarios to Gains

This section describes the process and results of obtained by putting the SEEScen energy scenario data into IIASA's GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model. GAINS calculates the effect of energy options on greenhouse gas emissions, but this module is not used here. GAINS is used here to calculate air pollution emission and emission control costs as determined by energy flows, vehicle stocks and traffic, and assumptions about control measures. The two main sections below describe issues arising in transferring the SEEScen data into GAINS, and the emission and cost results from GAINS.

SEEScen and GAINS are complex models and there are large amounts of data to transfer from SEEScen to GAINS. The categorisation and definitions of data are sometimes incompatible and so data have to be adjusted, aggregated and disaggregated. Furthermore, the author is not a trained expert in the use of GAINS and the interpretation of its results. These factors can lead to mistakes and inaccuracies, any of which, in this document, are solely the responsibility of the author.

7.1. Transferring SEEScen scenario data to GAINS

GAINS WEB contains several emission scenarios, Scenarios are grouped into versions, which document progress of the work on the scenarios. Each emission scenario combines assumptions about:

- Activity pathways that are specified for the following types of economic activity: Energy, Transport , Agriculture , Industrial processes and VOC (volatile organic compounds)-specific sources. Activities are specified variously: for example, as energy flows, as vehicle kilometres, or as industrial production.
- Control strategy that determines penetration of emission control technologies for every emission sector. In particular, the "Current legislation" (CLE) strategy reflects the controls that need to be applied to comply with the already decided national and international emission, fuel quality, and product standards.
- Emission vector that stores the information about (country-specific) emission factors and other coefficients for every activity/sector/control technology combination.

Certain of the SEEScen scenario data have to be transferred to GAINS:

- Energy flows in all the major stationary and mobile sectors.
- Vehicle distances and numbers.
- All other data in the GAINS input files are unaltered.

A number of issues arise when transferring data from the SEEScen scenarios to GAINS, the most significant of these are:

- Mapping. A general problem is that categories and their definitions are not all identical in databases used by SEEScen, GAINS, IEA and other national databases. Particular difficulties included:
- Disaggregating total power station fuel consumption for each fuel (e.g. coal) between subclasses (e.g. hard coal, lignite, peat) and between old and new power station types; in GAINS; PP_EX_WB, PP_EX_OTH, PP_NEW.
- Disaggregating diesel and gasoline fuel consumption, fleet numbers, and vehicle distance between cars, small buses, LDVs and trucks.
- Quantification. Energy flows are generally first measured in original units (e.g. tonnes of coal) and then converted to energy (PJ) using energy contents (GJ/tonne). Sometimes different energy contents are used.
- Historic data. The GAINS databases used have historical data to 2000, whereas, at the time this is written, SEEScen uses historical IEA data to 2004. Some energy flows have changed substantially over the period 2000-2004, and so the current GAINS projection for 2005, the first projection year, becomes infeasible for some flows. In these modelling exercises, the past catches up with the future and so the base year has to be regularly updated.

Key to these energy and environment scenarios comparisons are the differences between them in terms of energy flows, CO_2 emissions, the costs of controlling non-CO_2 emissions, rather than the absolute numbers. This consideration, and the issues listed above, have led to the following approach being taken:

i. Use GAINS 2000 as the base data. These data have been subject to scrutiny by IIASA and national experts.
ii. Aggregate SEEScen flows by GAINS categories; e.g. the GAINS category DOM is an aggregate of the residential and services/commercial sectors which are separate in SEEScen.
iii. Use SEEScen scenarios to generate indices of change from 2000, e.g. the change in diesel consumption of cars 2000 to 2005, 2000 to 2010, etc.
iv. Account for the difference between GAINS 2000 and SEEScen 2004 data with a correction factor.
v. Project GAINS 2000 data forwards using the SEEScen indices.
vi. Where SEEScen does not have disaggregated data, subdivide SEEScen aggregate using GAINS proportions. For example; SEEScen produces total future coal burn in power stations in PJ. This is converted to an index of 2000, and then applied to GAINS 2000 data for different coal types (brown coal-BC1 etc.) and power plant types (power plants existing wet bottom- PP_EX_WB, existing other- PP_EX_OTH, and new- PP_NEW). This ensures that historical data match and that the

apportioning is as in GAINS, but it does not ensure that the future proportioning is correct.

This approach is not perfect, but it should result in reasonably reliable estimation of the differences between scenarios. The problems noted above could largely be resolved with further work, but it is to be remembered that scenarios of the future are never certain in any case.

7.2. Results from GAINS

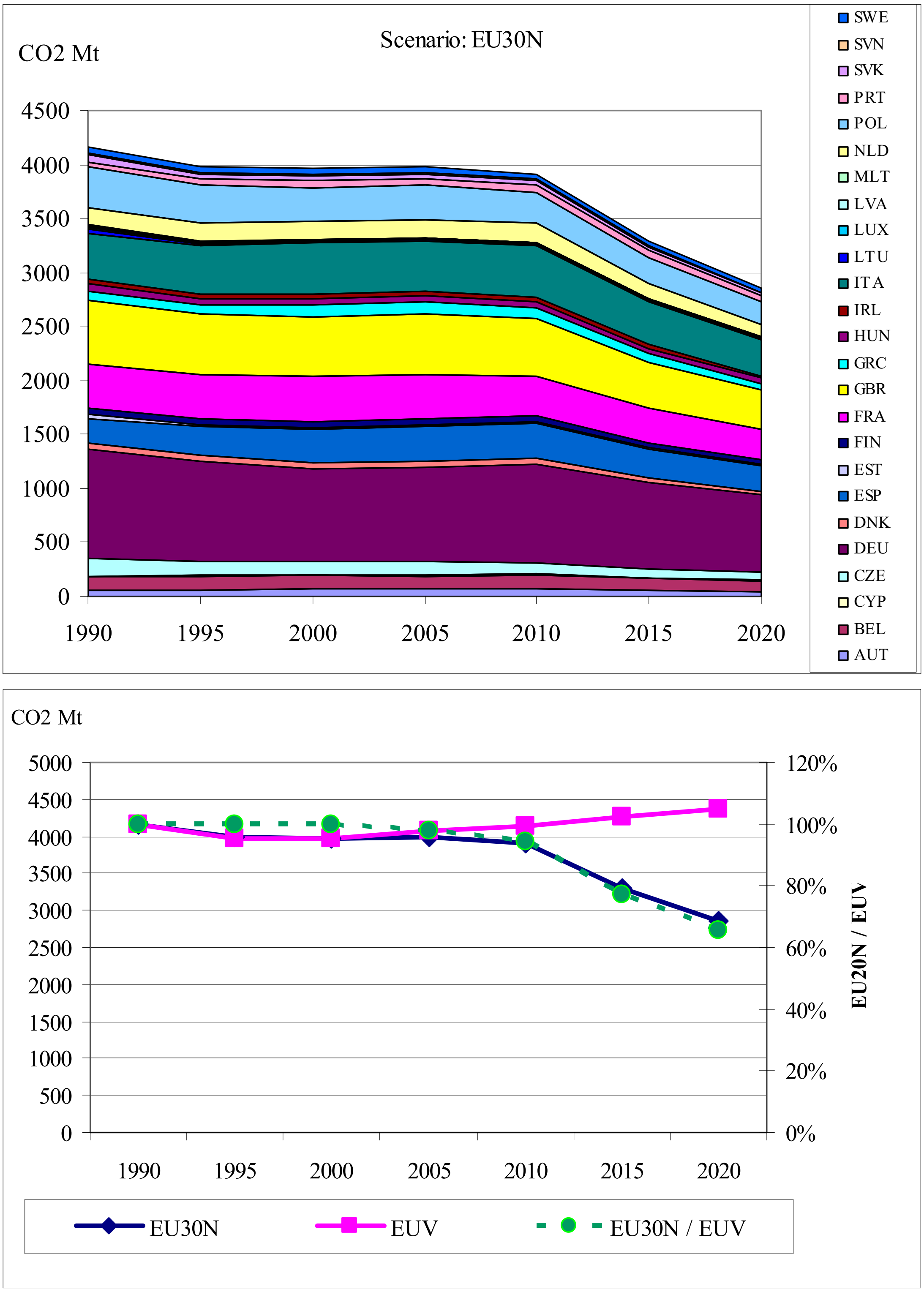
This section presents the results of running the SEEScen **EU30pc20N** scenario (labelled **EU30N** in this section) through GAINS. The comparison are made with the NAT_EUV_HDV GAINS scenario available under Scenario Group NEC03; this is labelled **EUV** below. the NAT_EUV_HDV GAINS scenario. This scenario, methodology and data are described by Amann et al (March 2007).

It should be noted that the differences in the emissions and control cost results given below arise only because of differences in energy scenarios, and in fossil energy combustion in particular. Emissions and control costs arising from other processes should be the same in the two scenarios. Therefore the emission and cost differences for energy alone would generally be larger than the results quoted blow.

7.2.1. GAINS CO_2

Running SEEScen **EU30N** through GAINS gives similar results for CO_2 emissions, with **EU30N** having 30% less emission in 2020 than **EUV**.

Figure 45 EU30N / EUV scenarios - CO_2 emission



7.2.2. GAINS NO_x

The **EU30N** scenario result in 20% less NO_x emission in 2020 than **EUV**, with control costs about 5% less.

Figure 46 EU30N / EUV scenarios - NO_x emission

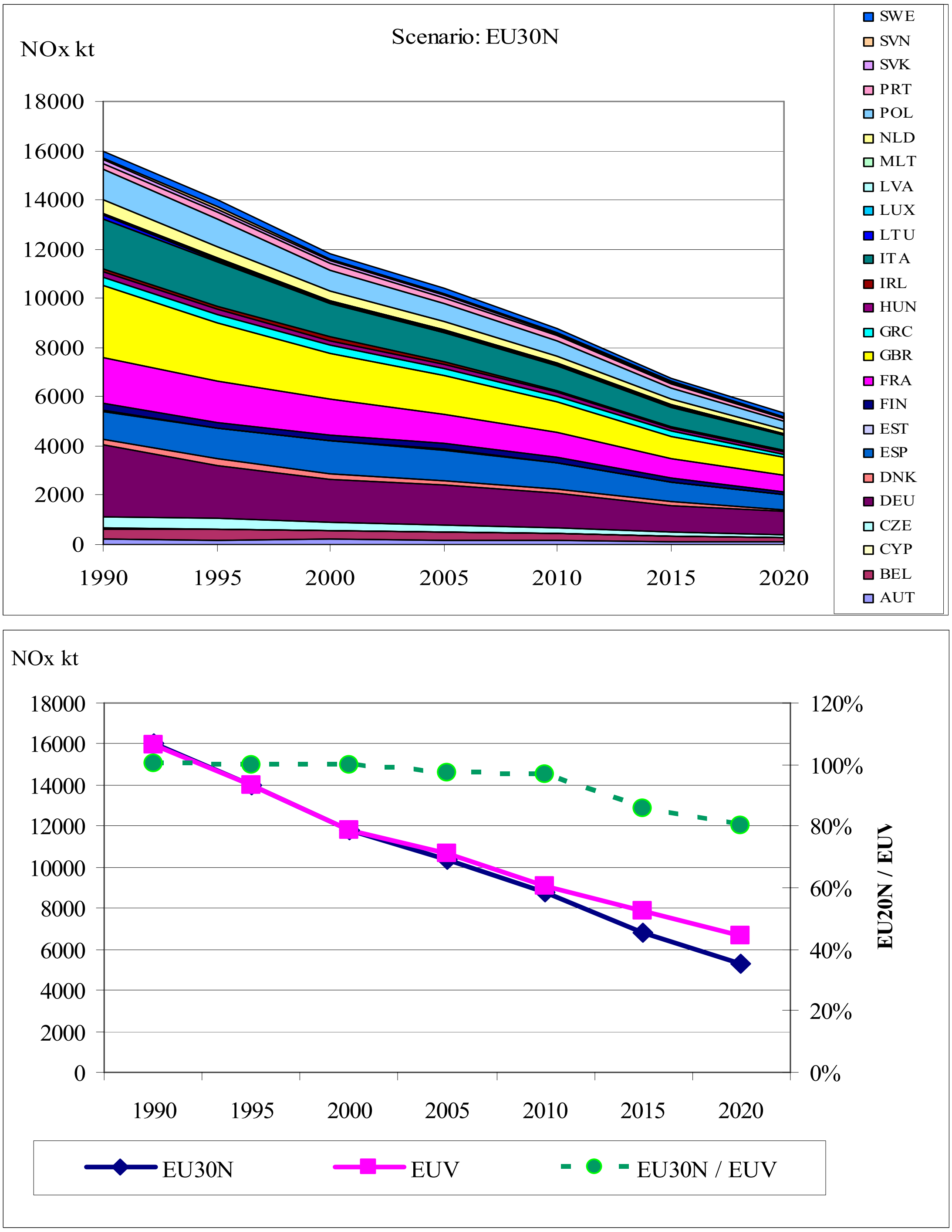
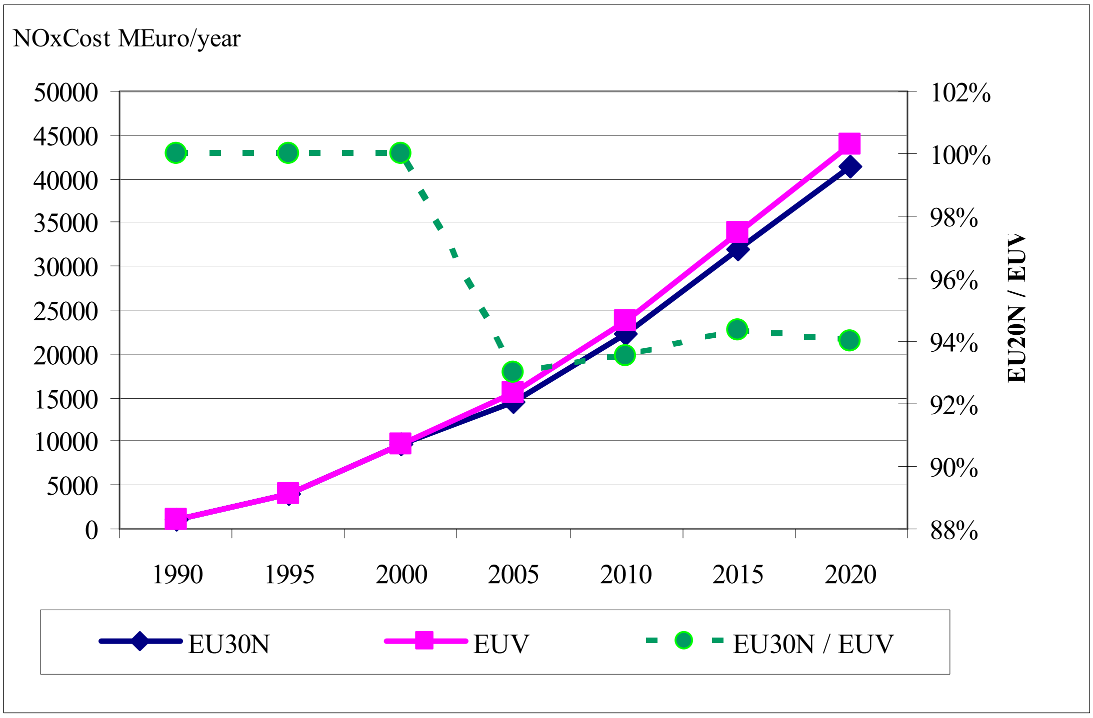


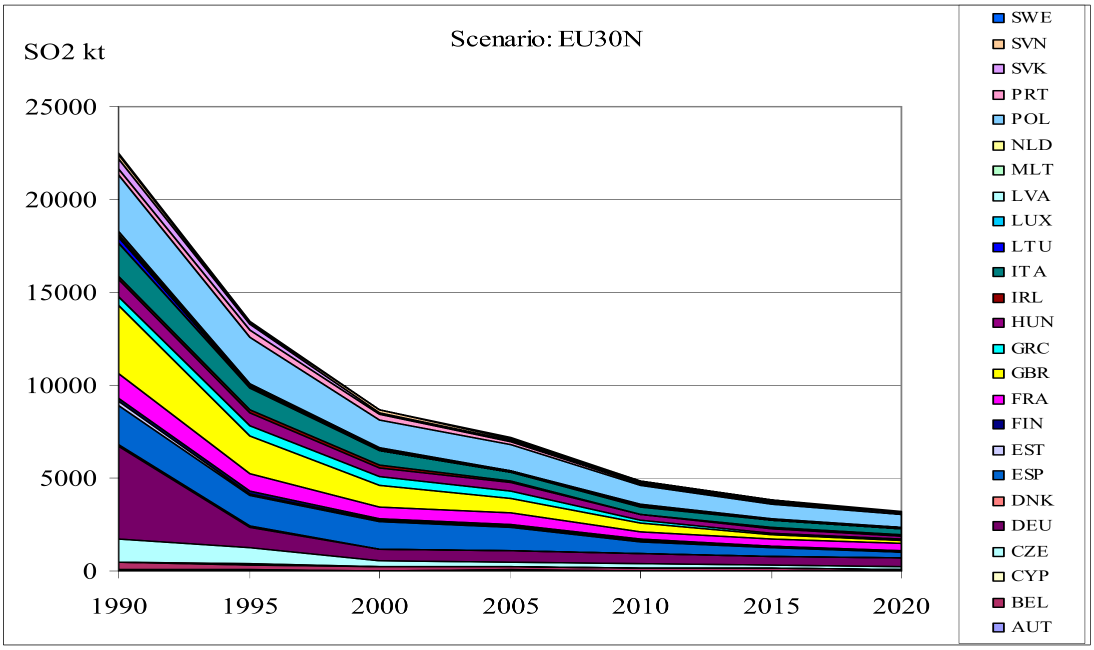
Figure 47 EU30N / EUV scenarios - NO_x EOP control costs



7.2.3. GAINS SO_2

The **EU30N** scenario results in 20% less SO_2 emission in 2020, with control costs reduced by a similar amount.

Figure 48 EU30N / EUV scenarios – SO_2 emission



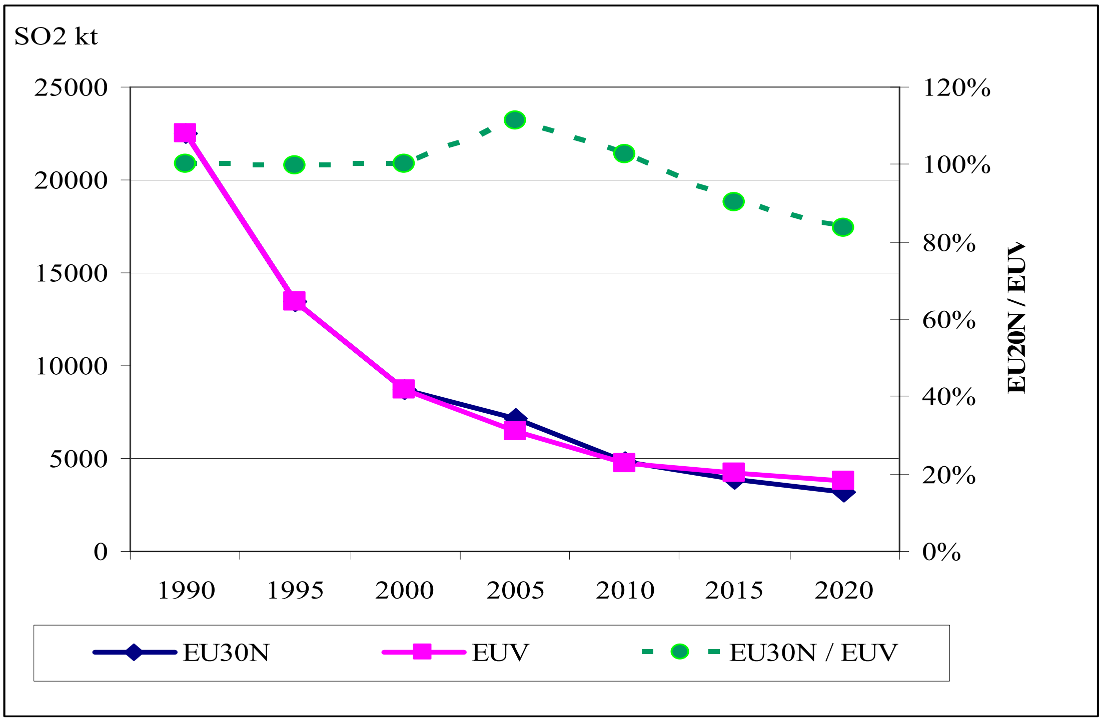
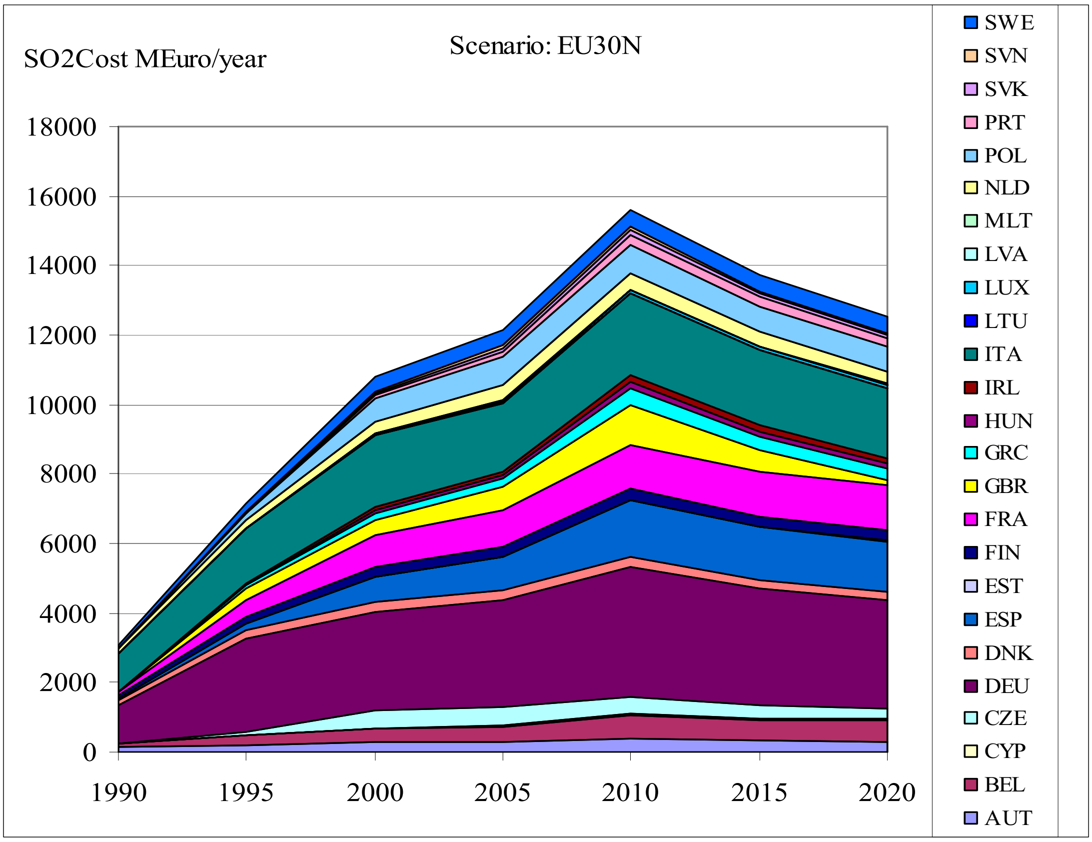


Figure 49 EU30N / EUV scenarios – SO_2 EOP control costs



7.2.4. GAINS VOC

The **EU30N** scenario results in 3 or 4% less VOC emission in 2020 than the **EUV** scenario, with control costs reduced by a similar amount.

Figure 50 EU30N / EUV scenarios - VOC emission

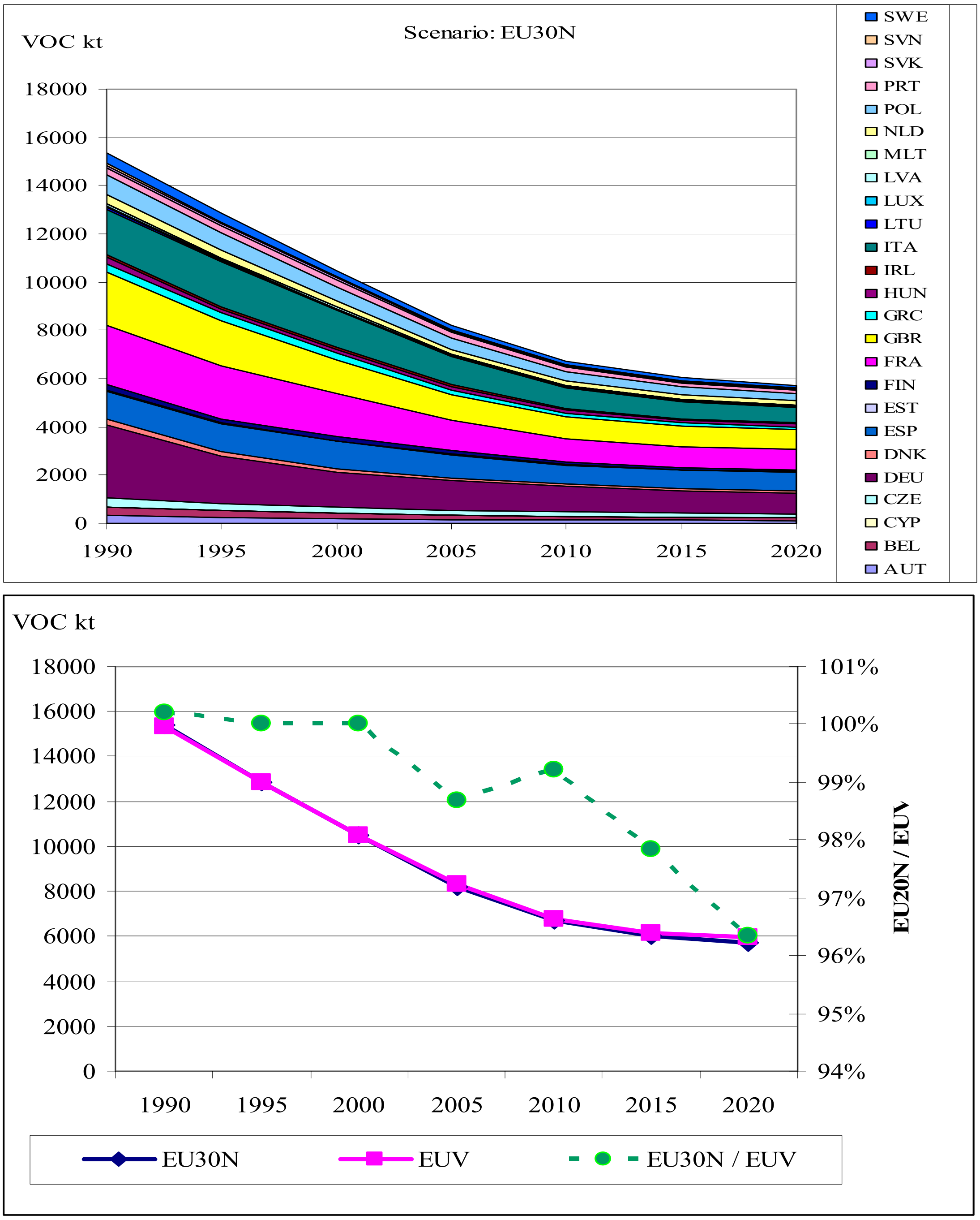
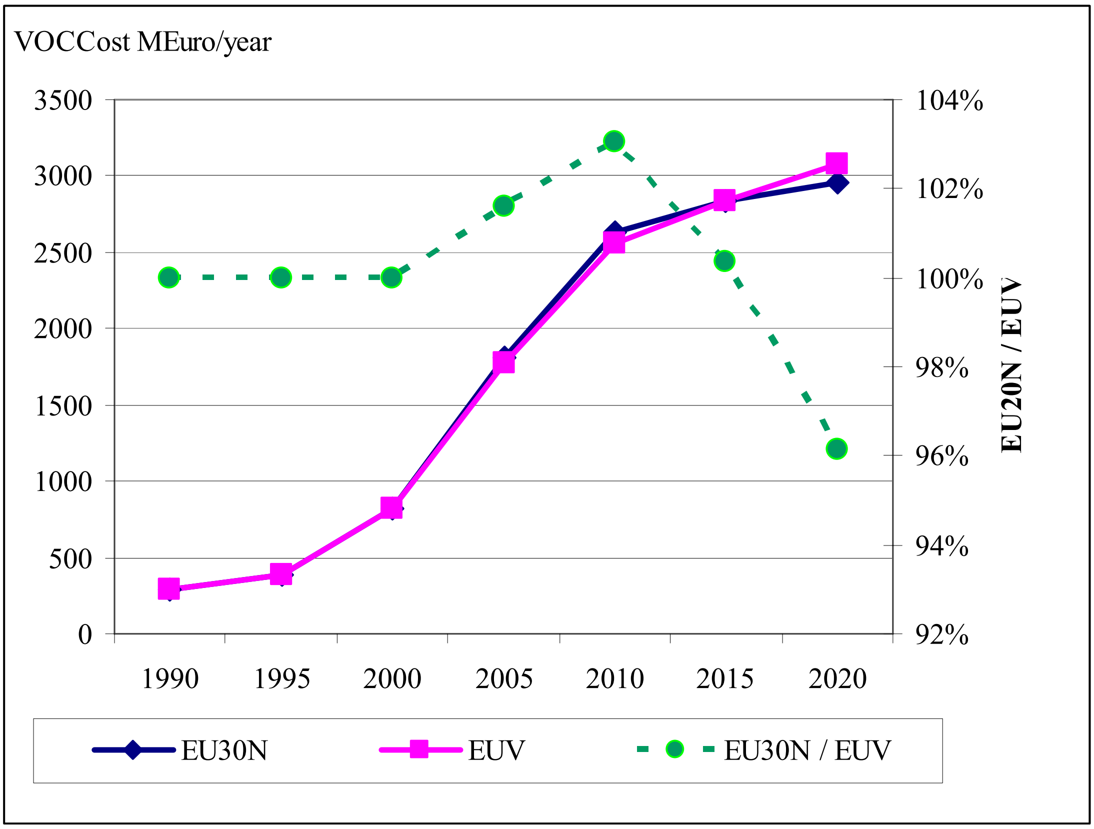


Figure 51 EU30N / EUV scenarios - VOC EOP control costs



7.2.5. GAINS PM

The **EU30N** scenario results in about 5% less PM emission in 2020 than the **EUV** scenario, with control costs reduced by about 20%.

Figure 52 EU30N / EUV scenarios - PM emission

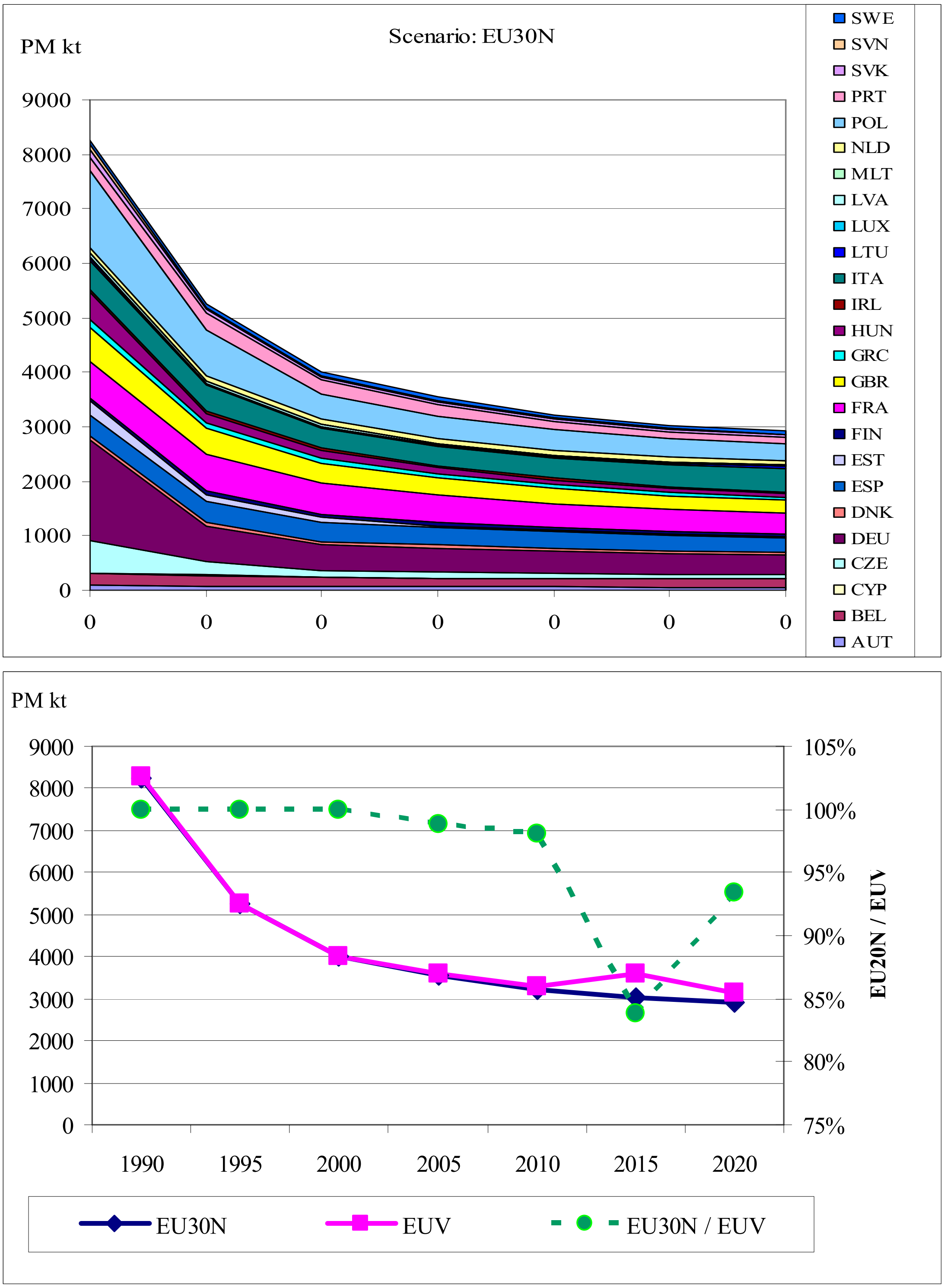
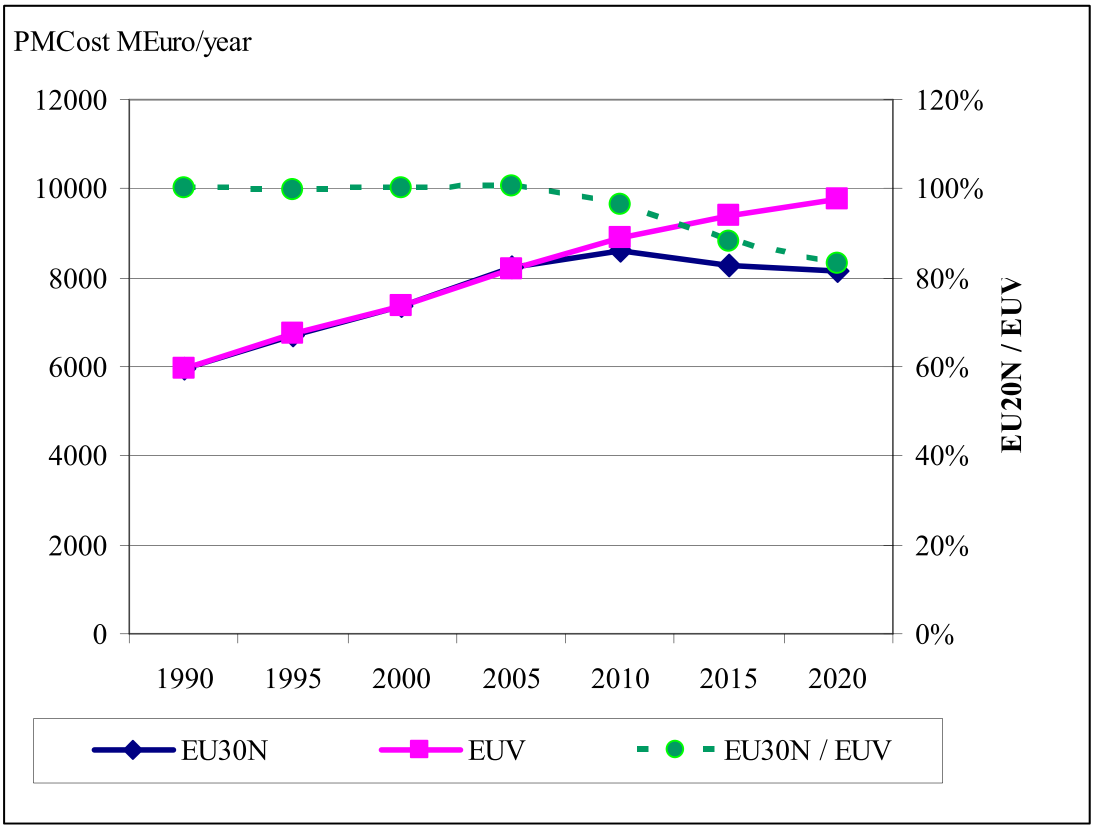


Figure 53 EU30N / EUV scenarios - PM EOP control costs



7.3. Commentary

The **EU30N** energy scenario results in lower emissions and control costs for all pollutants than in the **EUV** scenario as is summarised in the next Table.

Table 9 Summary of SEEScen to GAINS results for 2020

	EUV	**EU30N**	**Reduction EUV-EU30N**
Emission (kt)			
NO_x	6643	5321	20%
SO_2	3831	3203	16%
VOC	5942	5725	4%
PM	3123	2917	7%
Control cost (MEuro/a)			
NO_x	43990	41345	6%
SO_2	16298	12531	23%
VOC	3072	2954	4%
PM	9758	8135	17%
Total	**73118**	**64965**	**11%**

It is probable that emissions and control costs incurred by the **EU30N** energy scenario would actually be lower than those presented here. Further work is required to determine whether this is so, and what the magnitude of further reduction might be, but the reasons for this view are advanced below.

Emissions from power stations are likely to be overestimated. This is because the plant with the highest emissions per energy produced would be displaced first. A study of Large Point Sources of emissions by Barrett (2004) shows how the emissions per electricity and heat produced by power plant vary very widely because of different fuels, efficiencies and emission controls. In the transition to low or zero emission CHP and renewable electricity production, it will be possible to first reduce production from the worst, high emitting plants. The degree to which this is possible is determined by a complex of factors including the power plant stock, electricity transmission, free trading and demand profiles.

The crude apportioning of SEEScen total power plant fuel consumption to the GAINS categories does not yet account for this displacement at all. And within these categories the range of emission per kWh can be large.

Some emissions from vehicles are estimated using vehicle distances and emission factors in g/km based on Euro standards and vehicles operating under certain driving cycles. The SEEScen **EU30N** scenario assumes some downsizing of cars, reduction in motorway speeds and modal shift from car to rail and bus which will predominantly reduce urban car use and congestion. These measures will generally result in less air pollution per energy consumed and per distance travelled by cars. If these factors are not accounted for, the result may be the overestimation of air pollution emissions airing from the **EU30N** scenario in GAINS. The control costs for smaller cars are less than for large ones, and this would result in lower total control costs than a fleet of larger cars. It should also be noted that it is feasible to reduce air pollution emissions for a small, low fuel consumption car to below those for a large car as exhaust emissions are approximately related to fuel consumption. The change in transport mode and the use of electric vehicles will predominantly reduce urban car emissions.

It is to be expected that the differences in the scenarios would become more marked in the years 2020 to 2050 as **EU30N** diverges further from ‘conventional’ higher carbon scenarios.

8. Conclusions

These scenarios for 25 countries were developed over a relatively short period of time. Experts in each country will generally have better data for their countries, and a superior understanding of the best mix of measures and the potential for CO_2 reduction. However, these scenarios apply the same NEOP measures in a consistent manner across all countries using a single model. In doing this there are fewer problems ensuring comparable results than using country scenarios generated with a range of models.

These scenarios help to identify where the largest problems arise concerning CO_2 reduction, and what the best solutions to these might be. The scenarios show how measures can simultaneously address the problems of air pollution, carbon dioxide emissions and energy security.

8.1. Results

ENERGY AND CO_2

- International aviation and shipping should be included in the EU25 emissions inventory, otherwise the CO_2 reduction strategy could become imbalanced.
- Large energy demand reductions are feasible in most sectors.
- Behavioural change is important, especially in car choice and use, and air travel demand.
- There is a shift from fossil fuel heating, especially gas, to solar and electric heat pumps.
- Fossil electricity generation can be replaced by a mix of renewables to the extent that Europe might become a net exporter of renewable electricity.
- The most intractable problem is replacing fossil liquid transport fuels, especially for aircraft and ships.

AIR POLLUTION EMISSION

- The low carbon measures allow for further reductions in ari pollution, and a decrease in the EOP costs of achieving any particular target.
- The emissions and costs calculated using GAINS are probably pessimistic because of technical issues concerning the transfer of data between SEEScen and GAINS.

8.2. Feasibility of scenarios

The feasibility of the scenarios may be assessed from a number of perspectives: technical, economic and behavioural.

- Technical aspects. In most countries the measures are not implemented to the maximum and therefore, if the maxima are approximately correct, the scenarios are technically feasible from this perspective. The rate of introduction of the measures is to a degree not a technical issue, since extra expenditure can increase the rate of implementation over the 'natural rate'. The question of whether the EU will be able to import gas and oil as required in the scenarios is a question that needs analysis of global demand and supply to answer; however, it is clear that the lower the demand for these fuels, the less the problem will be.

- Behavioural issues. Key to the EU30pc20N scenarios are assumed changes to the stocks of consumer technologies in terms of efficiency and fuels used. This implicitly assumes certain consumer behaviour in terms of technology and fuel choice.
- Instruments. Emission targets cannot be achieved unless additional measures are implemented using instruments such as regulation and market measures. Instruments have not be analysed in this study, but it is clear that the tailoring of instruments to effectively implement measures requires further thought as any low carbon scenario requires substantial and rapid changes to the current policy stance and instruments in many, if not all EU countries.

8.3. Data and modelling

There are many facets of data and modelling that could be improved. Some of the more significant items are listed below.

8.3.1. Data

- **IEA energy statistics**. This is perhaps the single most useful dataset for modelling. However, there are problems such as accounting for energy inputs and outputs to cogeneration.
- **General demand management and efficiency potential**. The estimates of the savings to be made through demand management and efficiency are based on specific and general studies. Some of these studies are old, and some countries are not covered.
- **Renewable energy**. Surveys of the technical and economic potential of the different renewable energies are required.

8.3.2. Energy modelling

DEMAND

The demand for useful energy is the foundation of any energy scenario. The model changes the demand for useful energy according to functions based on per capita GDP and population. At present these functions do not account for factors such as:

- Age structure and activity of population. Apart from households becoming smaller, the average age of Europeans is increasing and their patterns of economic activity will change because of this, and other economic trends.
- Changes in expenditure pattern. The energy intensity of many goods and commodities purchased at the margin can decrease as wealth increases:

> once people have houses and cars, further marginal 'optional' expenditure may go into less carbon intensive goods and services such as electronic goods; alternatively it may go on carbon intensive goods or services such as luxury cars or long distance holidays. Such changes in final consumption also tend to be reflected in a restructuring of the economy such that an increasing proportion of value added is realised in the tertiary or services sector, and a decreasing proportion in primary and secondary industrial sectors. For some, but not all, goods and services produced by the services sector the energy consumption per value added is less than in heavy industries.

These issues require further careful analysis. If simple growth functions without saturation are assumed in the model are used, energy demand increases inexorably in the long term after the potential technical savings are fully taken up.

SUPPLY

More detailed modelling of energy supply would be helpful. This particularly relates to electricity systems with high fractions of renewable energy.

9. Reference Materials

9.1. References

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9.2. Reference materials

Further material that may be of interest can be found at the links below.

UK Energy scenario: presentation
http://www.bartlett.ucl.ac.uk/markbarrett/Energy/UKEnergy/UKEneScenarioAnim140206.zip

Renewable electricity system: Feasibility of a high renewable electricity system

http://www.cbes.ucl.ac.uk/projects/energyreview/Bartlett%20Response%20to%20Energy%20Review%20-%20electricity.pdf

Transport:

Summary presentation of some Auto-Oil work on transport and air quality, including some non-technical measures.

http://www.bartlett.ucl.ac.uk/markbarrett/Transport/Land/AutoOil/JCAPWork.ppt

Large Point Sources: emissions and health effects.

http://www.acidrain.org/pages/publications/reports.asp

http://www.bartlett.ucl.ac.uk/markbarrett/Environment/LPS/LPS.htm

General:

http://www.bartlett.ucl.ac.uk/markbarrett/Index.html

Appendix 1. Emission Burden Sharing

A possible approach and issues arising are discussed below simply as a contribution to the development of a framework for burden sharing: this approach is **not** used in the scenarios.

For 2020, an approach could be to scale the 2010 target with this rule:

Country emission target for 2020 = Country emission target for 2010 * EU target 2020 (index)/EU target 2010 (index).

A general ethical principle may be advanced of equal rights of humans to the global atmosphere, so that GHG emission (in this case, tonnes of CO_2) per capita should converge to the same figure. This convergence should be tempered by factors such as:

- The influence of climate and geography on energy demands.
- In some countries, the potential for introducing emission controlling technologies such as insulation or hydropower may have already been largely realised, reducing the scope for further implementation.

It is beyond the scope of this study to account for the above factors . The Kyoto commitments and per capita indices for fossil fuel CO_2 emission may then be apportioned on a sliding scale so that in 2020 the target is derived by the above rule, whereas for 2050 it is purely convergence on per capita emission; in intervening years, a combination of the two is applied. The consequences of this are as follows.

The next Figure and Table show the change in emission index (1990) for each country.

Figure 54 Fossil fuel CO_2 emission index to 1990

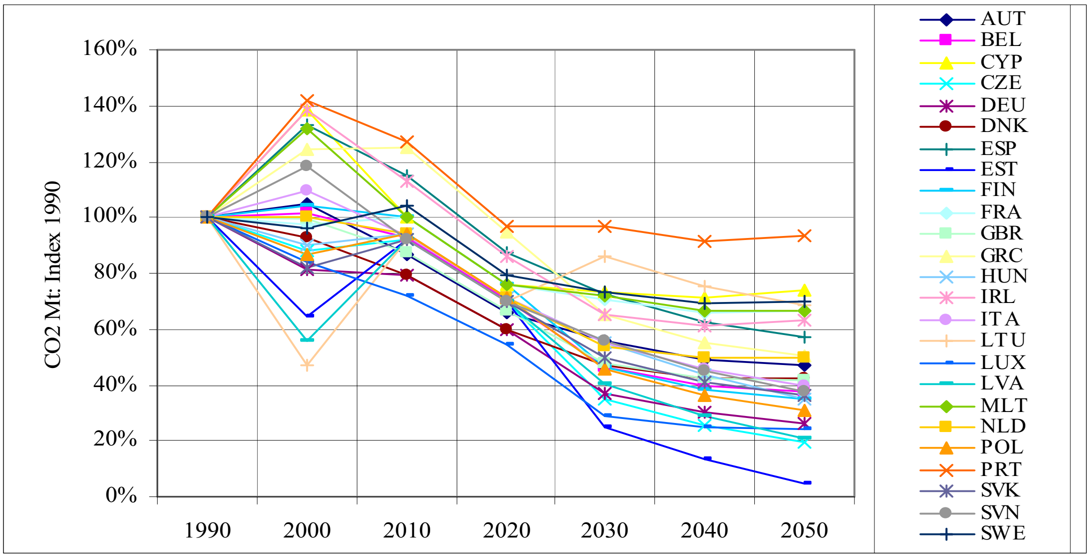


Table 10 CO_2 targets: index of 1990 emissions (EU30pc20)

	Kyoto	**This study**			
	2010	**2020**	**2030**	**2040**	**2050**
AUT	87%	66%	40%	22%	9%
BEL	93%	70%	42%	23%	10%
DNK	79%	60%	36%	20%	8%
FIN	100%	76%	45%	25%	11%
FRA	100%	76%	45%	25%	11%
DEU	79%	60%	36%	20%	8%
GRC	125%	95%	57%	31%	13%
IRL	113%	86%	51%	28%	12%
ITA	94%	71%	43%	23%	10%
LUX	72%	55%	33%	18%	8%
NLD	94%	72%	43%	23%	10%
PRT	127%	97%	58%	31%	14%
ESP	115%	88%	52%	28%	12%
SWE	104%	79%	47%	26%	11%
GBR	88%	67%	40%	22%	9%
HUN	94%	72%	43%	23%	10%
CZE	92%	70%	42%	23%	10%
EST	92%	70%	42%	23%	10%
LTU	92%	70%	42%	23%	10%
LVA	92%	70%	42%	23%	10%
POL	94%	72%	43%	23%	10%
SVK	92%	70%	42%	23%	10%
SVN	92%	70%	42%	23%	10%
CYP	100%	76%	45%	25%	11%
MLT	100%	76%	45%	25%	11%

The CO_2 emission per capita for each country converges to a single figure by 2050. These country emission targets result in total country and EU25 fossil fuel CO_2 profiles. These are shown in the next two Figures.

Figure 55 Fossil fuel CO_2 per capita (EU30pc20)

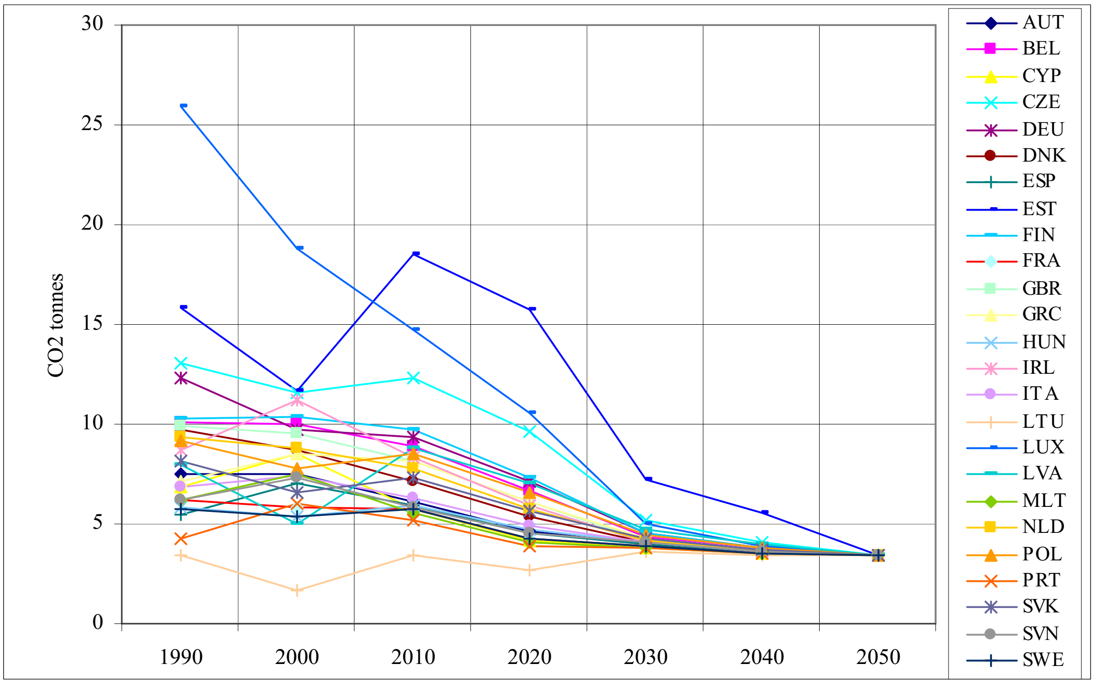
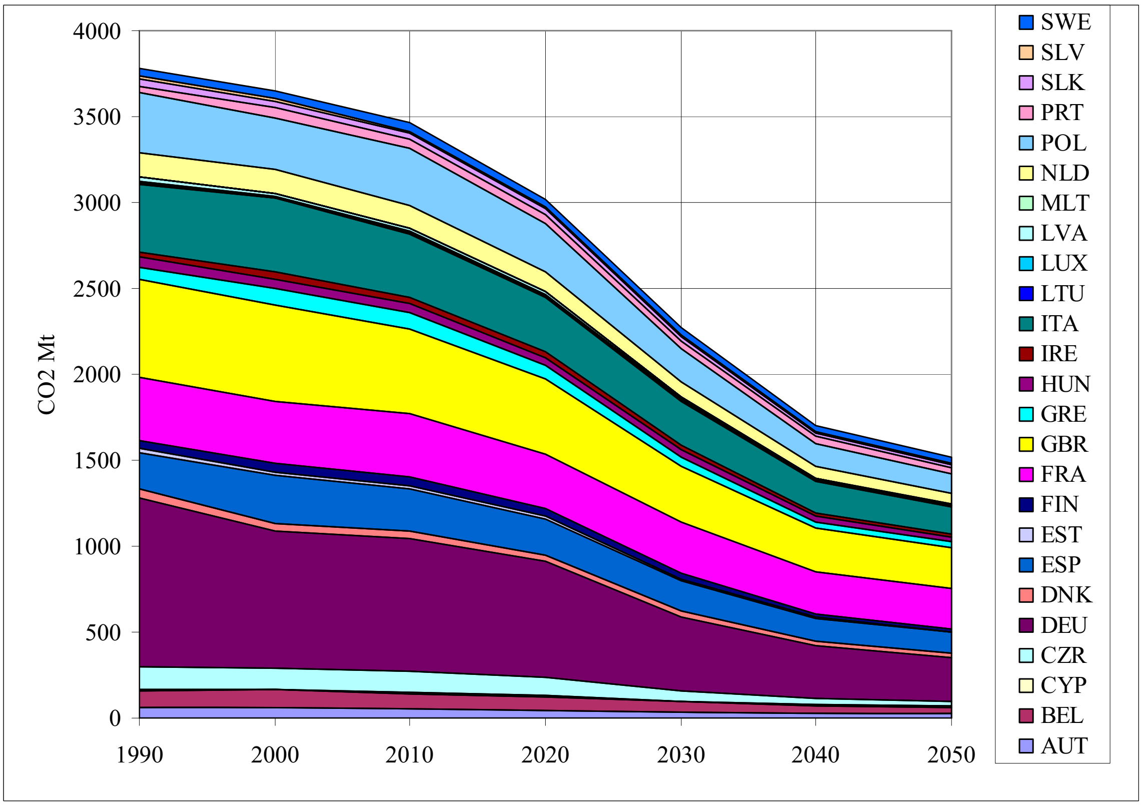


Figure 56 EU25 fossil fuel CO_2 target



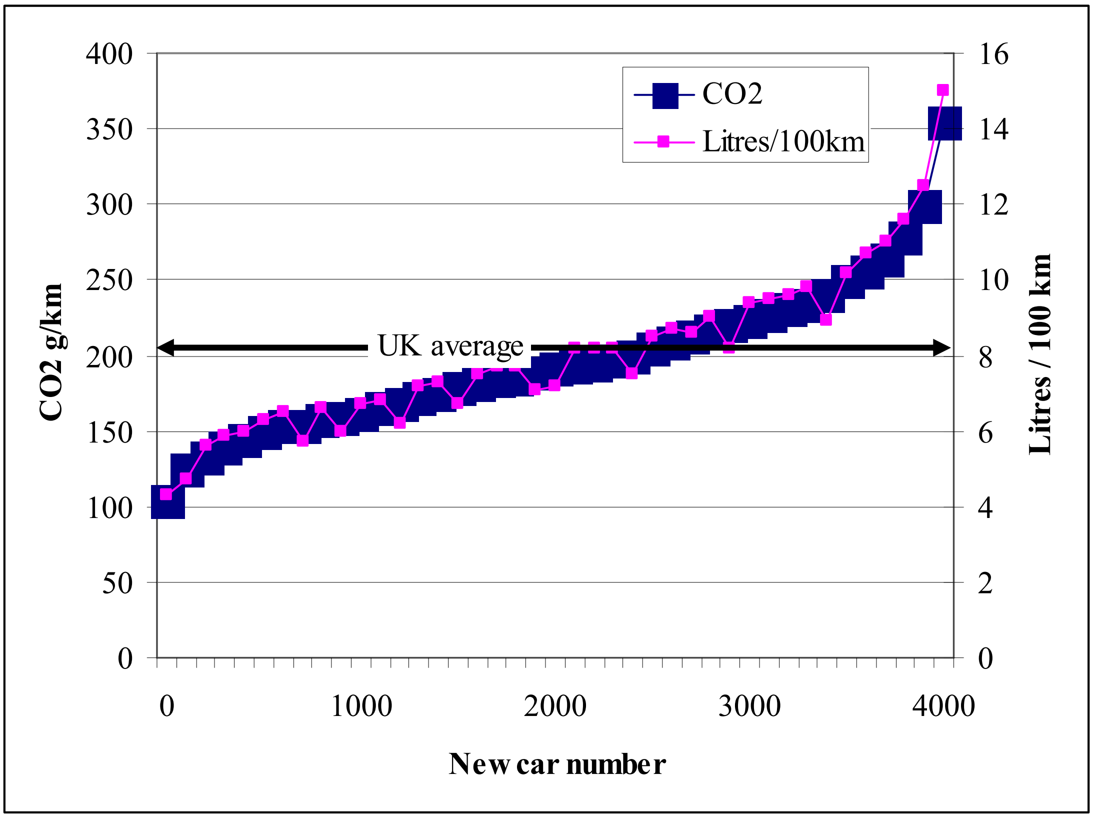
Appendix 2. Vehicle Emissions

There is a large potential CO_2 emission reduction if consumers choose smaller cars, and it is possible to achieve lower emissions of other pollutants with fuel efficient cars. Substantial emission reductions may be realised through reductions in motorway speeds. The turnover of the car stock is about 15 years, and speeds could be reduced in a few years.

CO_2 emission

In the UK the average fuel consumption of cars (litres/100 km) is roughly stable at about 9.1 l/100 km whilst the average fuel consumption of new cars is marginally decreasing and is currently about 8.7 l/100 km (DfT, 2006). Congestion and speeding are important factors in the lack of progress in reducing fuel consumption and related CO_2 emissions. The UK car fleet average CO_2 emission is about 225 g/km. The next Figure shows the consumption and emissions of 4000 new cars on the market (VCA, 2007); the horizontal arrow shows the current average emissions and consumption.

Figure 57 Car fuel consumption and CO_2 emission

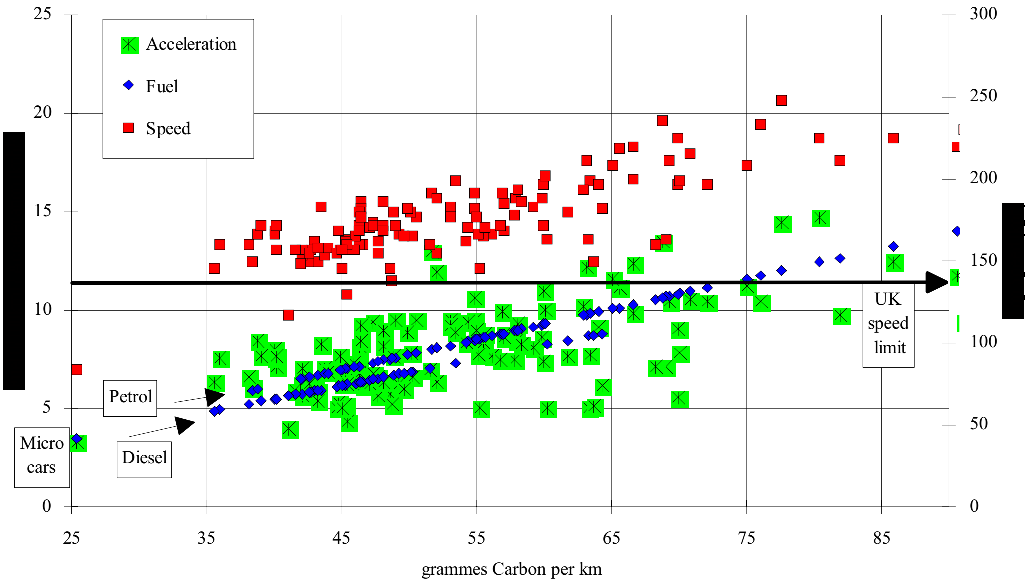


Source: VCA, 2007

Smaller cars like the Toyota Prius and Citroen C1 have combined cycle consumptions of about 4 l/100 km and CO_2 emissions of 104 g/km. The 4/5 seat Audi A2 1.2 TDI, no longer produced, has a top speed of 168 kph (100 mph), combined consumption of 3 litres/100 km (94 miles per gallon) and emission of 81 gCO_2 / km. Therefore, downsizing to the Audi would reduce the UK fleet CO_2 emissions

by about 64%. Cars account for about 13% of total UK CO_2 emission, so downsizing to the Audi could reduce UK CO_2 emission by about 8% in 15 years, the average life of a car. Cars even more fuel-efficient than the Audi have been made.
In general, the fuel use and emissions of cars are related to the performance in terms of top speed and acceleration. This is illustrated with a selection of cars in the next Figure. Micro cars are represented by the points close to the y-axis.

Figure 58 Car carbon emission and performance

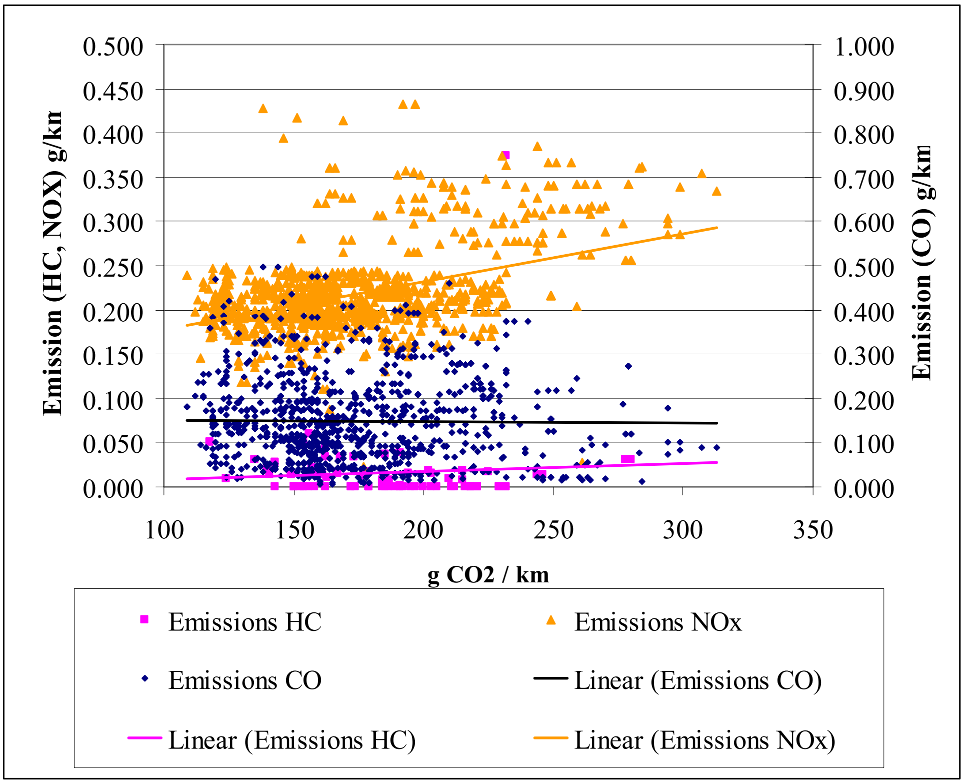


Source: VCA, 1994; manufacturers data.

Air pollution emission

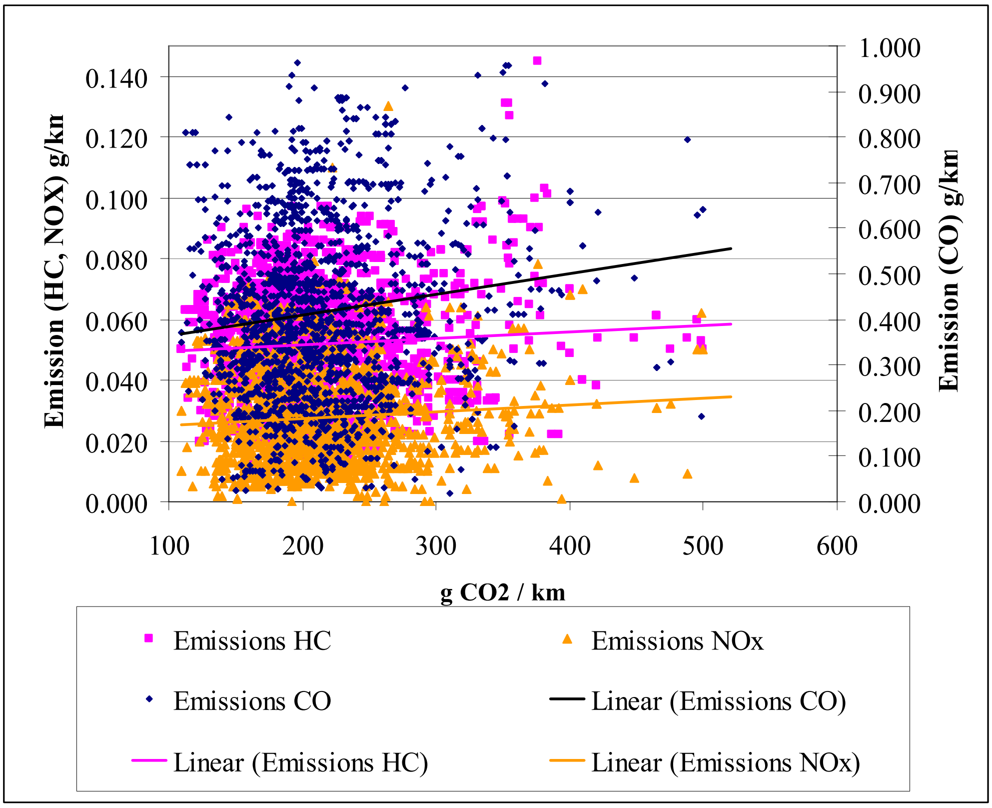
The following Figures show the correlation of NO_x, HC and CO with CO_2 emission for 4000 new diesel and petrol cars on the market (VCA, 2007).

Figure 59 Car pollution and CO_2 emission : diesel cars



Source: VCA, 2007

Figure 60 Car pollution and CO_2 emission : petrol cars



Source: VCA, 2007

It is not certain how these emission data, obtained from standard test cycles, translate to actual on road emissions; but two things are clear:

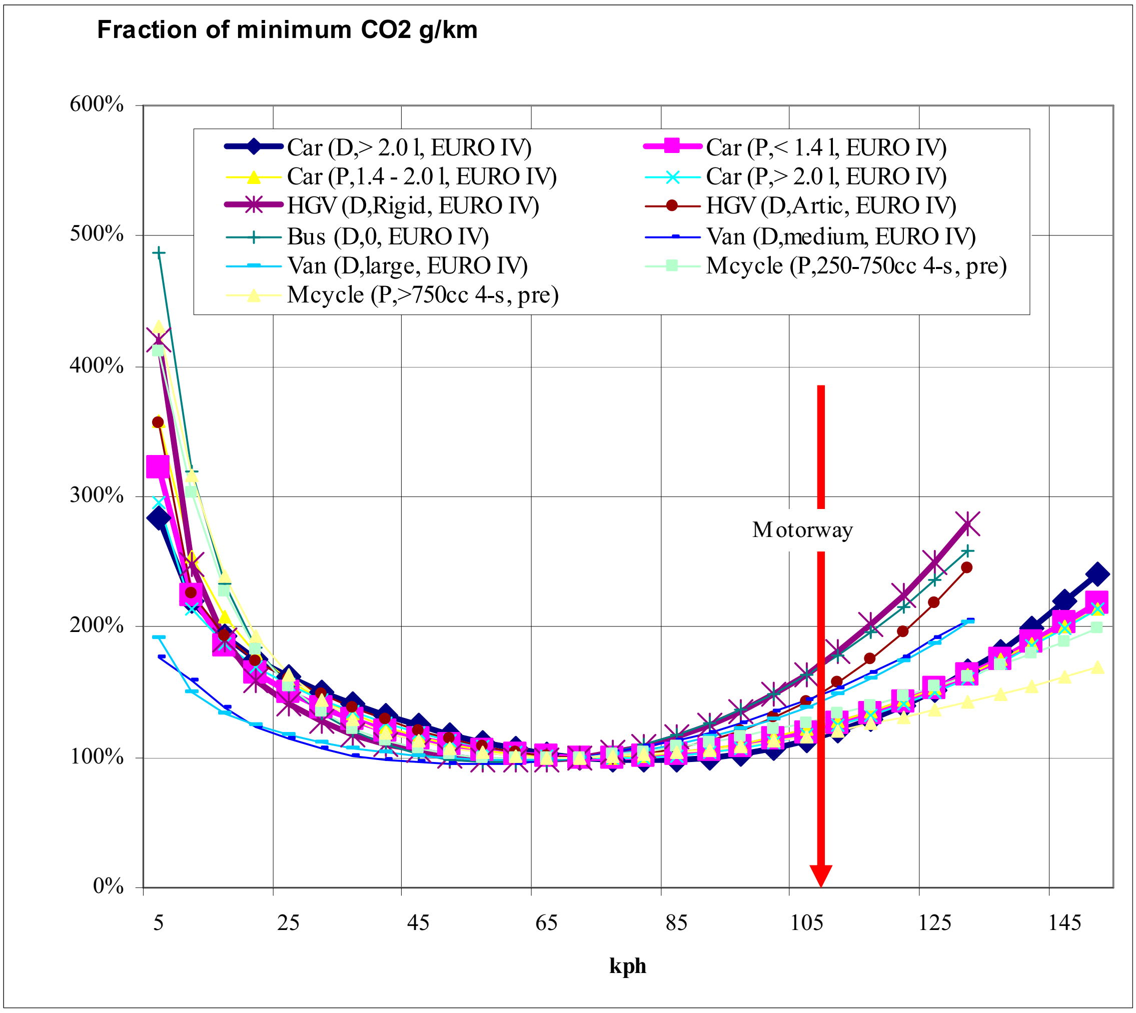
- The emissions of air pollutants are positively correlated to CO_2 emission
- For a given CO_2 emission in g/km the range of air pollution emission is very large, with the best cars emitting a small fraction of the worst. The Figures indicate that switching to the lowest emitting cars for a given CO_2 emission would reduce NO_x, HC and CO emission by over 50%.

In general, for a given technology system (engine-fuel-emission control), the emissions of pollutants (SO_2, NO_x, PM, VOC) are approximately related to fuel use. Therefore the emission of these pollutants would be reduced by about 50% if the same emission control levels were applied to small as to large cars.

Emission and speed

Energy use and carbon emissions increase strongly at higher speeds as is shown in the next Figure. Curves for other pollutants are generally similar, because emission is strongly related to fuel consumption. These curves are only applicable to current vehicles. The characteristics of future vehicles (e.g. urban internal combustion and electric powered) would be different. The minimum emission would probably be at a lower speed, and the fuel consumption and emissions at low speeds would not show the same increase as for current cars. Potentially, the lowering of actual speeds on fast roads might reduce emissions on those roads by perhaps 10-20%.

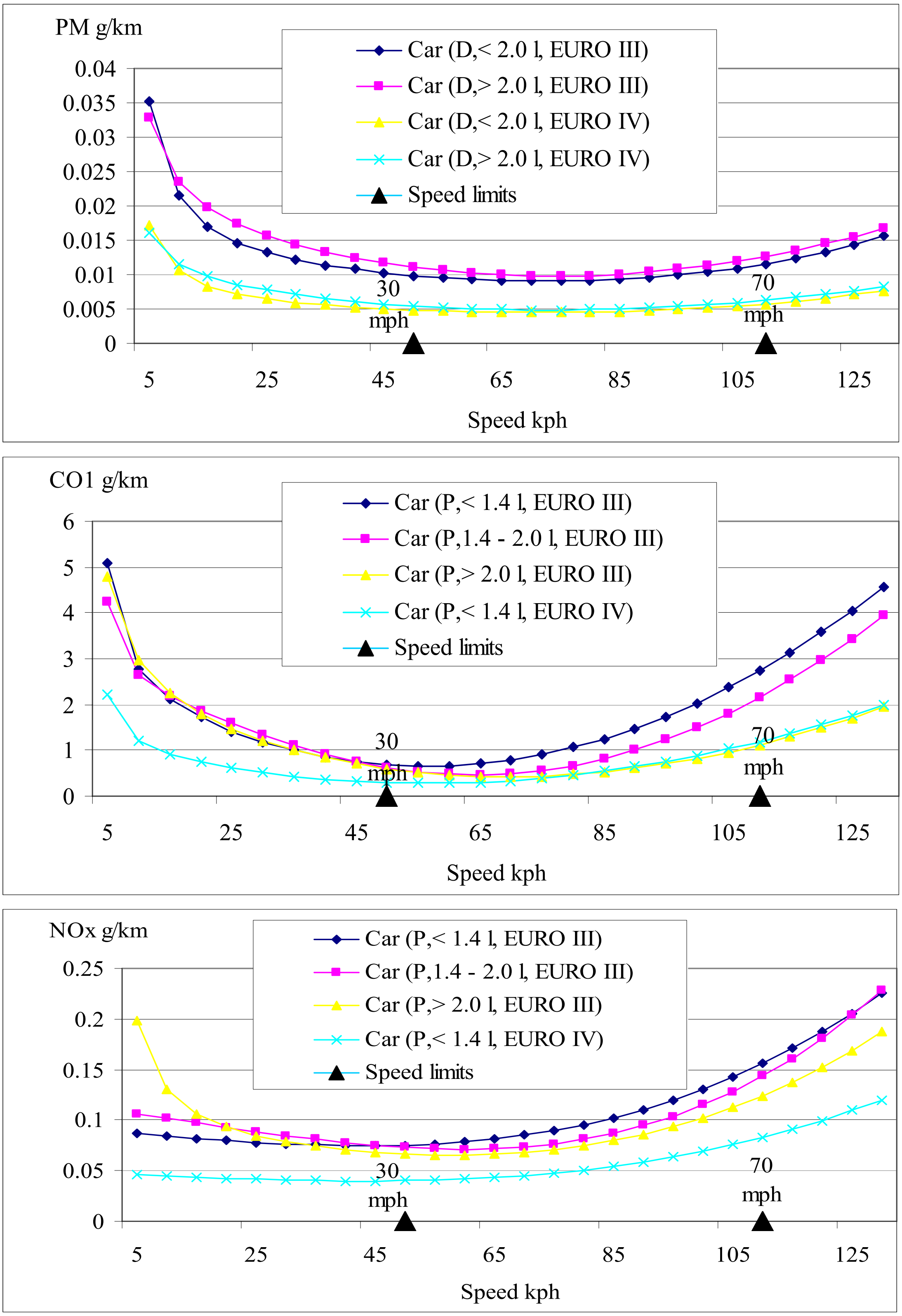
Figure 61 Vehicle carbon emission and speed



Source: AEAT, 2005

Apart from CO_2, SEEScen does not currently account for the variations in other emissions due to the use of technologies. The emissions of PM, NO_x and carbon monoxide generally increase at higher speeds as is shown in the following Figures. Plainly, the reduction of high speeds would significantly reduce emission. So also, would increasing the lower speeds; this could be facilitated by reducing car use and congestion.

Figure 62 Vehicle pollutant emission and speed – PM, CO, NO_x



Appendix 3. Renewable Energy Fraction

INTRODUCTION

This appendix addresses the issue of quantifying the contribution of renewable energy in national energy systems in scenarios developed using the SEEScen model.

The European Council has agreed to set a target for renewable energy for EU: 20% of energy should be from renewable sources by 2020. This raises the problem of how to estimate the renewable energy fraction of total EU energy consumption. These questions arise:

- Where in the energy flow system of a country is renewable energy measured?
- Which renewable energy sources are included?
- How are the renewable energy flows quantified and accounted?
- How is the fraction of renewable energy calculated?

This appendix reports the Council agreement, discusses answers to these questions and presents estimates of renewable fractions for a SEEScen scenario.

Emphasis in the quotes used is the author's and is shown **bold and underlined**.

Council agreement

The EU commitment o renewable energy is stated in the document *Brussels European Council 8/9 March 2007, Presidency Conclusions* (Council of the European Union, 2007). The following quotes from this.

"5. The European Council is aware of the growing demand for energy and increasing energy prices as well as of the benefits of strong and early common international action on climate change, is confident that a substantive development of energy efficiency and of renewable energies will enhance energy security, curb the projected rise in energy prices and reduce greenhouse gas emissions in line with the EU's ambitions for the period beyond 2012, and underlines that the energy savings objective and targets for renewables and biofuels referred to below should be achieved with a view to sharing efforts and benefits fairly and equitably among all Member States, taking into account different national circumstances, starting points and potentials.

7. The European Council reaffirms the Community's long-term commitment to the EU-wide development of renewable energies beyond 2010, underlines that all types of renewable energies, when used in a cost-efficient way, contribute simultaneously to security of supply, competitiveness and sustainability, and is convinced of the paramount importance of giving a clear signal to industry, investors, innovators and researchers. For these reasons, taking into consideration different individual circumstances, starting points and potentials, it endorses the following targets:

*− a binding target of a 20 % share of renewable energies in **overall EU energy consumption** by 2020;*

− a 10 % binding minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption by 2020, to be introduced in a cost-efficient way. The binding character of this target is appropriate subject to production being sustainable, second-generation biofuels becoming commercially available and the Fuel Quality Directive being amended accordingly to allow for adequate levels of blending.

From the overall renewables target, differentiated national overall targets should be derived with Member States' full involvement with due regard to a fair and adequate allocation taking account of different national starting points and potentials, including the existing level of renewable energies and energy mix (cf. paragraphs 10 and 11), and, subject to meeting the minimum biofuels target in each Member State, leaving it to Member States to decide on national targets for each specific sector of renewable energies (electricity, heating and cooling, biofuels).

In order to meet these targets, the European Council:

− calls for an overall coherent framework for renewable energies which could be established on the basis of a Commission proposal in 2007 for a new comprehensive directive on the use of all renewable energy resources. This proposal should be in line with other Community legislation and could contain provisions as regards:

= Member States' overall national targets;

= National Action Plans containing sectoral targets and measures to meet them; and

= criteria and provisions to ensure sustainable production and use of bioenergy and to avoid conflicts between different uses of biomass."

CONVENTIONS

The aim is to reduce the environmental impacts (global warming, air pollution, etc.) incurred in providing energy services (heating, lighting, transport, etc.). One option to do this is increasing energy supply from renewable sources – solar, wind, hydro, etc. so as to displace fossil fuels which are a major cause of global warming. In order to drive this option forward, the Council has set renewable energy targets as a fraction of energy supply.

The problem is that defining this fraction in a clear and useful way such that it can be applied to all countries now and in the coming decades is difficult, if not impossible. This will make it difficult to define a renewable target, and to determine whether it has been reached . Furthermore, the definitions and conventions used strongly affect how energy from different renewable sources (hydro, wind, solar, etc) is quantified, and this will make it difficult to negotiate burden sharing of the overall 20% target. For example, the current convention assigns a greater primary energy value (about twice) to 1 GJ of heat from biomass combustion than to 1 GJ of hydro electricity, despite the fact that the 1 GJ of energy has the same utility; in fact, the hydro electricity could be input to a heat pump to produce 2 or 3 GJ of heat.

ELECTRICITY SUPPLY

Assume that 1 extra TWh of electricity is generated from renewable sources, and that it displaces 1 TWh of fossil generated electricity. This TWh will reduce fossil fuel consumption by an amount dependent on the efficiency of the plant it replaces: if gas, then it will reduce gas consumed for that amount of generation by about 2 TWh (gas to electricity efficiency about 50%); if coal, then by about 3 TWh (efficiency about 35%). The fraction of fuel inputs to generation that an increment of renewable electricity displaces plainly depends on the pre-existing mix of generation – fossil, nuclear and renewable. An increase of 20% in electricity generated by renewable sources might reduce fossil energy inputs to generation by 40%, or 100%.

If a country with 100% nuclear and hydro increased renewable output, fossil generation fuel savings in that country would be zero: in this case, the extra electricity would be absorbed by increasing electricity demand in that country, or by exporting, both of which would displace fossil fuels in other sectors or countries. This raises a further issue of dealing with import and export.

The problem is further complicated by the fact that the type and efficiency of fossil generation displaced by renewable energy varies across the day and year. For a given electricity system, 1 TWh of wind electricity will displace a different amount of fossil fuel from 1 TWh of solar PV electricity. In general, in Europe, the least efficient high carbon plant operate more in the winter than the summer.

HEAT SUPPLY

Solar water heating will displace other heating fuels such as gas or electricity. 1 GJ of useful heat from a solar heater will displace 1.2 GJ of gas input to a condensing gas boiler (efficiency 80%), 2 GJ of gas into an old gas boiler (efficiency 50%), or 1 GJ of electricity into an electric immersion heater (efficiency about 100%). Where it displaces 1 GJ of electricity, this in turn will displace any fossil fuels used to generate that GJ – perhaps 3 GJ of coal.

These examples illustrate these points:

- The fraction of total energy provided by renewable energy depends on a number of assumptions and conventions which are only useful for particular energy systems in a particular year.
- The amounts of fossil and other energy forms displaced by renewable energy depend on the overall energy system, which is different for different countries, and which changes across the years.
- The fraction of renewable energy in a given system will in general be different depending where in the system this is measured.

In general, the current conventions exaggerate the utility of energy provided by processes involving heat (fossil fuels, nuclear generation, geothermal, biomass combustion) and underplay the utility of those that do not involve heat (wind, wave, tidal, solar PV electricity) or which directly supply heat (solar thermal collection). Here, the word utility means the capacity to displace fossil fuels, and to provide energy services. Whether the current conventions will exaggerate the overall renewable energy contribution in a particular energy system depends on the mix of energy forms and fuel at all stages in that system. A system with a large fraction of biomass and geothermal would achieve a higher renewable fraction as compared to one with high hydro and wind, and some cases, even if the latter delivered more useful energy.

Depending on the overall mix of renewable energy supply, it is quite possible that the current conventions underestimate the contribution of renewables to displacing fossil fuels.

A number of other questions arise, for example:

- The heat extracted from the environment by heat pumps is renewable, should this be counted as renewable energy? This could be a critical issue, as the use of electric heat pumps may well expand as gas supplies become more scarce and expensive.
- Should the fraction of biofuels be of total energy delivered to vehicles? In which case, how is the electricity to electric vehicles dealt with given that a GJ of electricity provides about twice as much energy at the wheels of a car as a GJ of biodiesel?
- Is electricity produced from biomass CHP plant and input to an electric vehicle counted as a biofuel?

A number of documents discuss these issues and definitions in a general way. Gallachoir et al (2006) discuss the general issues with respect to the situation in Ireland; and SenterNovem (2004) similarly for the Netherlands. Riederer (2006) describes some possible approaches to accounting for renewable heat.

In addition, the European Commission, the European Environment Agency, and the International Energy Agency provide some descriptions of how the renewable fraction should be calculated. These are summarised below.

ENERGY FOR THE FUTURE: RENEWABLE SOURCES OF ENERGY

In the document Energy for the Future: Renewable Sources of Energy (European Commission, 1997), it is stated:

> *"In the Green Paper on Renewables the Commission sought views on the setting of an indicative objective of 12% for the contribution by renewable sources of energy to the European Union's gross inland energy consumption by 2010"*

This document proposes that passive solar gains "should be counted in the balance of the European Union's gross energy consumption."

RENEWABLE ENERGY ROAD MAP

In the Renewable Energy Road Map: Renewable energies in the 21st century: building a more sustainable future (European Commission, 2007), it is stated:

> *"It proposes that the EU establish a mandatory (legally binding) target of 20% for renewable energy's share of energy consumption in the EU by 2020..."*
>
> *"In 1997, the European Union started working towards a target of a 12% share of renewable energy in gross inland consumption by 2010 represent-*

> *ing a doubling of the contribution from renewable energies compared with 1997. Since then, renewable energies have increased their contribution by 55% in absolute energy terms.*
> *"A considerably bigger contribution from renewable energy sources to reach the 12% target, which is expressed as a percentage of overall energy consumption (as opposed to a share of overall energy production) is thus required. Also, the fact that the 12% objective is expressed as a percentage of primary energy, penalises the contribution of wind energy."*
> *"When the target was established in 1997 it was expected that a much smaller proportion of it would be realised by the contribution of wind compared to biomass. As biomass is a thermal process and wind is not, one unit of final energy produced from biomass counts 2.4 times more than one unit of final energy produced from wind and counted in primary energy."*

This commentary underlines how accounting conventions affect the nominal renewable energy contribution.

EUROPEAN ENVIRONMENT AGENCY (EEA)
The EEA Indicator Management Service (IMS) gives this specification:
(CSI 030) Specification - Renewable energy consumption.
http://ims.eionet.europa.eu/IMS/ISpecs/ISpecification20041007132201/full_spec

> *Indicator definition*
> *Renewable energy consumption is the ratio between the gross inland consumption of energy from renewable sources and the total gross inland energy consumption calculated for a calendar year. It is usually expressed as a percentage of the former to the latter. It measures the contribution of renewable energy sources to the total consumption of energy.*
> *To calculate the aggregate indicator for renewable energy, only 2 components are needed: that is, gross inland energy consumption (from all sources) and gross inland energy consumption from renewable sources. A more detailed breakdown of the specific renewable sources would include solar energy (solar heat and photovoltaic), biomass and waste (wood, MSW, biogas and biofuels), geothermal energy, hydropower and wind energy.*

IEA conventions

The International Energy Agency (IEA) Statistics Division provides information on the conventions used in its data. The following are extracts from the documentation for *Energy Balances of OECD Countries (2006 edition) and Energy Balances of Non-OECD Countries* (2006 edition).

C. Primary Energy Conventions
When constructing an energy balance, it is necessary to adopt conventions for primary energy from several sources such as nuclear, geothermal, solar, hydro, wind, etc. The two types of assumptions that have to be made are described below:

I. Choice of the primary energy form
For each of these sources, there is a need to define the form of primary energy to be considered; for instance, in the case of hydro energy, a choice must be made between the kinetic energy of falling water and the electricity produced. For nuclear energy, ***the choice is between the energy content of the nuclear fuel, the heat generated in the reactors and the electricity produced. For photovoltaic electricity, the choice is between the solar radiation received and the electricity produced.*** *The principle adopted by the IEA is that the primary energy form should be the first energy form downstream in the production process for which multiple energy uses are practical. The application of this principle leads to the choice of the following primary energy forms:*

- *Heat for nuclear, geothermal and solar thermal;*
- *Electricity for hydro, wind, tide/wave/ocean and solar photovoltaic.*

II. Calculation of the primary energy equivalent
There are essentially two methods that can be used to calculate the primary energy equivalent of the above energy sources: the partial substitution method and the physical energy content method.

The partial substitution method: In this method, the primary energy equivalent of the above sources of electricity generation represents the amount of energy that would be necessary to generate an identical amount of electricity in conventional thermal power plants. The primary energy equivalent is calculated using an average generating efficiency of these plants. ***This method has several shortcomings including the difficulty of choosing an appropriate generating efficiency and the fact that the partial substitution method is not relevant for countries with a high share of hydro electricity.*** *For these reasons, the IEA, as most of the international organisations, has now stopped using this method and adopted the physical energy content method.*

The physical energy content method: This method uses the physical energy content of the primary energy source as the primary energy equivalent. As a consequence, there is an obvious link between the principles adopted in defining the primary energy forms of energy sources and the primary energy equivalent of these sources. For instance, in the case of nuclear electricity production, as heat is the primary energy form selected by the IEA, the primary energy equivalent is the quantity of heat generated in the reactors. However, as the amount of heat produced is not always known, the IEA estimates the primary energy equivalent from the electricity generation by assuming an efficiency of 33%, which is the average of nuclear power plants in Europe. In the case of hydro, as electricity is the primary energy form selected, the primary energy equivalent is the physical energy content *of the electricity generated in the plant, which amounts to assuming an efficiency of 100%. A more detailed presentation of the assumptions used by the IEA in establishing its energy balances is given in Section 3.*

Since these two types of energy balances differ significantly in the treatment of electricity from solar, hydro, wind, etc., ***the share of renewables in total energy supply will appear to be very different depending on the method used****. As a result, when looking at the percentages of various energy sources in total supply, it is important to understand the underlying conventions that were used to calculate the primary energy balances.*
Please note, the method for calculating the primary energy content of electricity and heat from geothermal has been changed in the 2003 edition. Previously, an efficiency of 10% was assumed for geothermal electricity (if no country-specific information was available) whereas geothermal heat was counted at an efficiency of 100%. Now, if available, the actual heat inputs are used with the following defaults if no further information is available.

- *10% for geothermal electricity (unchanged)*
- *50% for geothermal heat.*

The IEA give further detail on the convention for electricity:

Electricity
Figures for electricity production, trade, and final consumption are calculated using the energy content of the electricity (i.e. at a rate of 1 TWh = 0.086 Mtoe). Hydro-electricity production (excluding pumped storage) and electricity produced by other non-thermal means (wind, tide/wave/ocean, photovoltaic, etc.) are accounted for similarly using 1 TWh = 0.086 Mtoe. ***However, the primary energy equivalent of nuclear electricity*** *is calculated from the gross generation by assuming a 33% conversion efficiency, i.e. 1 TWh = (0.086 ÷ 0.33) Mtoe. In the case of electricity produced from geothermal heat, if the actual geothermal efficiency is not known, then the primary equivalent is calculated assuming an efficiency of 10%, so 1 TWh = (0.086 ÷ 0.1) Mtoe.*

These extracts from the IEA energy accounting conventions illustrate how conventions can be misleading, arbitrary and inappropriate:

- Because nuclear generation entails heat production, one unit of nuclear electricity is counted as three times as much primary energy as one unit of wind, tidal, solar or wave electricity. Yet, to a first approximation, a unit of electricity will displace the same amount of fossil or other fuel in a particular system, whatever the source of that electricity.
- The primary equivalent of geothermal:
    - geothermal electricity has a primary equivalent 10 times that of hydro or wind electricity;
    - geothermal heat was doubled by changing the conventional efficiency from 100% to 50%, yet this will have had no real effect on energy flows and the displacement of fossil fuels.

SEESCEN SCENARIO RENEWABLE FRACTIONS

The renewable fractions in the SEECen scenario are calculated in this section.

Gross inland consumption or final consumption?

If final consumption is the measuring point for the renewable fraction then there is the problem of how to deal with upstream energy. For example, if 50% of electricity is generated from renewable sources then it seems logical to label 50% of electricity delivered to final consumers as renewable. But then there is the problem that electricity is more efficient at the point of use (about 100% if direct resistance heating; 200-300% if via a heat pump) than fossil fuels, say gas at 70%. The judgement taken here is that gross inland consumption is a better measure point for the renewable fraction than final consumption.

In principle, however, if renewable energy is added to an energy system, all of the upstream and downstream impacts should be calculated. For example; introducing biodiesel to cars will displace some mix of fossil fuels (diesel, gasoline, LPG, etc) and electricity from delivered energy. This in turn will change fuel and energy use upstream in distribution, refining and generation.

Renewable energy source included

The Table lists the principal renewable energy sources. Those included in this analysis are marked ‘x’.

Table 11 Renewable energy sources included

Primary source	Output	Technology	Included
Hydro	Elec	Turbine	x
Wind	Elec	Turbine	x
Wave	Elec	Various	x
Tide	Elec	Turbine	x
Sun	Heat	Active	x
		Passive	?
	Elec	PV	x
Biomass	Heat	Boiler	x
	Solid	Various	x
	Liquid	Various	x
	Gas	Various	x
Ambient heat	Heat	Heat pump	?

Primary equivalence

The question then is how to determine the renewable fraction; to use primary energy equivalents or some other method.

The main objective is to reduce the impacts of fossil fuel consumption with an emphasis on CO_2 emission. One method would be to estimate the CO_2 or fossil fuel saving of renewable energy by removing the renewable energy component from the energy system and seeing how much CO_2 increased assuming the energy were replaced by particular fossil fuels. This would have to be done for each year of a scenario, for each national energy system. This systems' approach is not possible within the scope of the present work.

Therefore the approach is taken of using primary energy equivalent efficiencies (PEeqe). This has the shortcomings described throughout the text above. The nuclear or renewable output is divided by the Primary Equivalent Efficiency to give primary energy equivalent. For example, 1 TWh of electricity from nuclear or renewable sources is equivalent to 1/40% = 2.5 TWh of primary energy.

For nuclear power and renewables, the next Table sets out the PEeqe for electricity, biofuels for transport and heat. The efficiencies are rather arbitrary; they might reflect 'average' EU values in 2020, but will certainly be inappropriate for some countries.

Table 12 Primary energy equivalence efficiencies

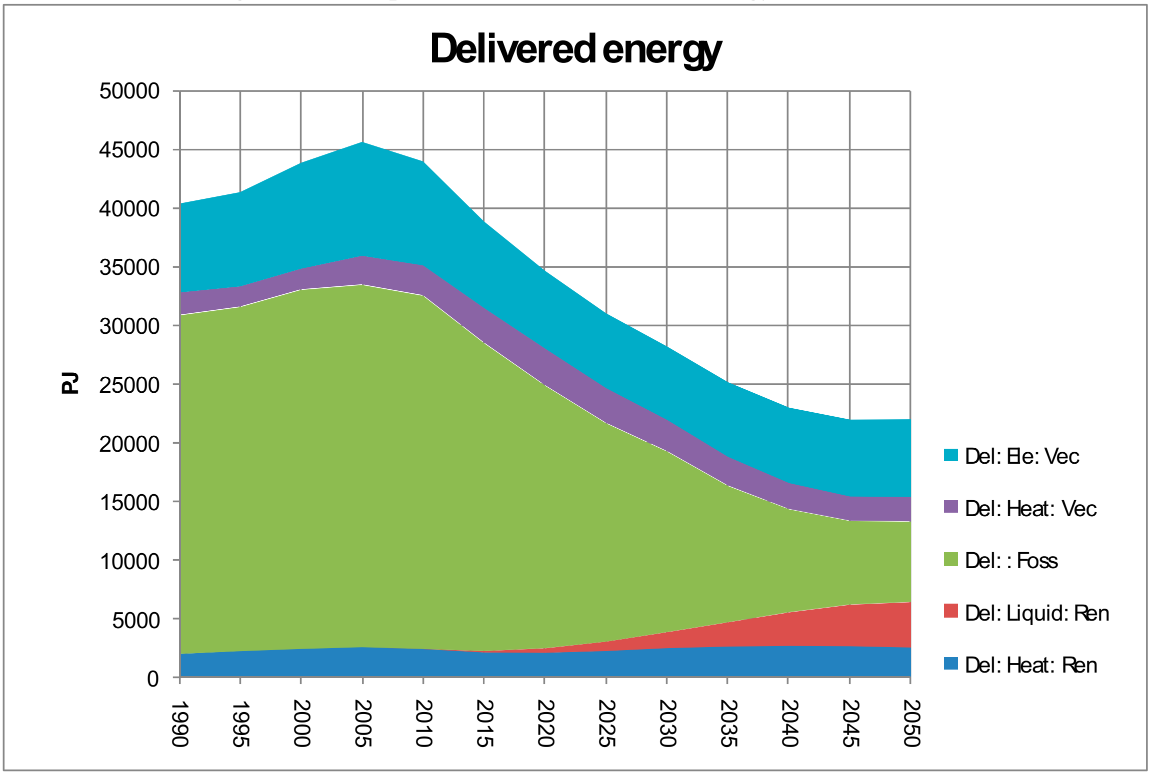
Type			**Primary Equivalent Efficiency**
Electricity	Generated		40%
Biofuels	Delivered	Transport	35%
Heat	Delivered	Solar	70%
		Biomass	70%
		Geothermal	70%
		Heat pump upgraded heat	70%

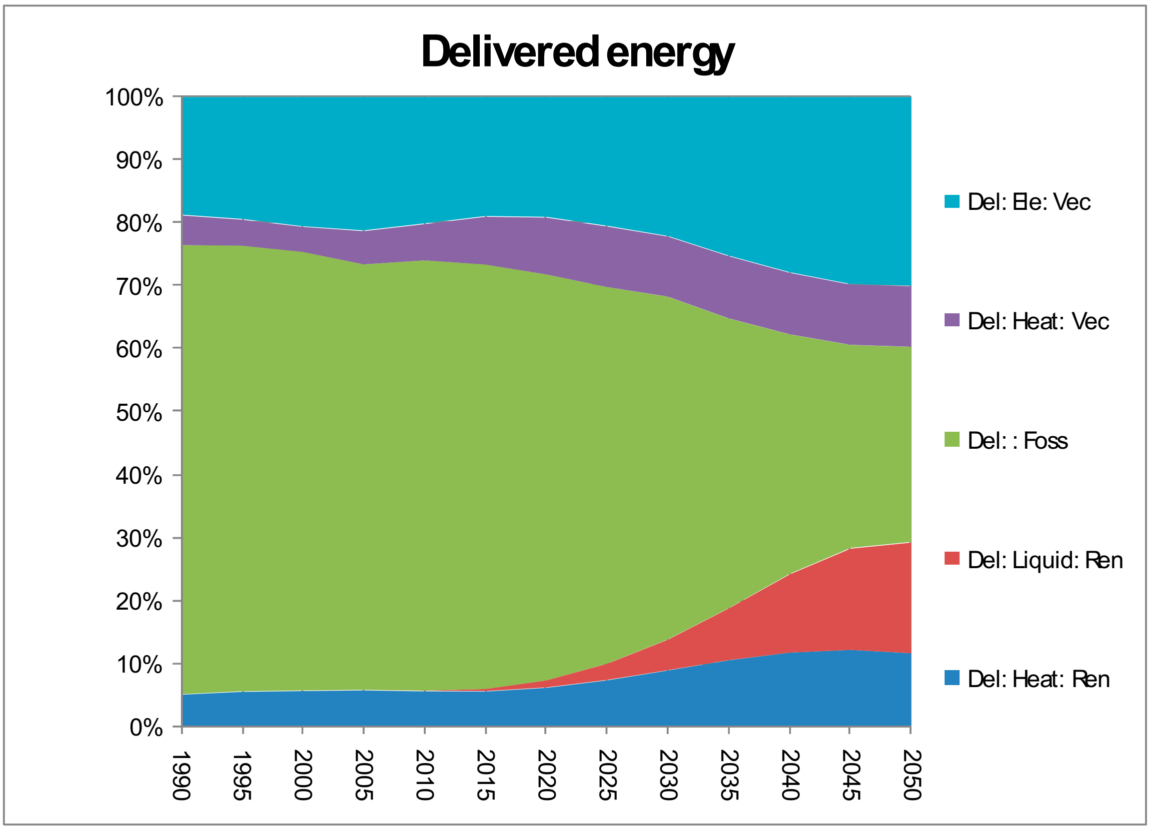
SEEScen renewable fractions

These equivalences were applied to the renewable and nuclear electricity flows in the SEEscen EU30pc20N scenario. This results in the energy flows shown in the next Figure. Using the conventions, renewable energy is 5% of delivered energy in 2020. Note that one reason for the increasing fraction is that the total energy deliveries decline because of energy efficiency.

LEGEND KEY	
Del: : Foss	Delivered fossil fuel
Del: Heat: Ren	End use biomass/solar heat
Del: Liquid: Ren	Delivered liquid
Del: Heat: Vec	Delivered heat vector (district heating)
Del: Ele: Vec	Delivered electricity vector

Figure 63 EU30pc20N scenario ; delivered energy

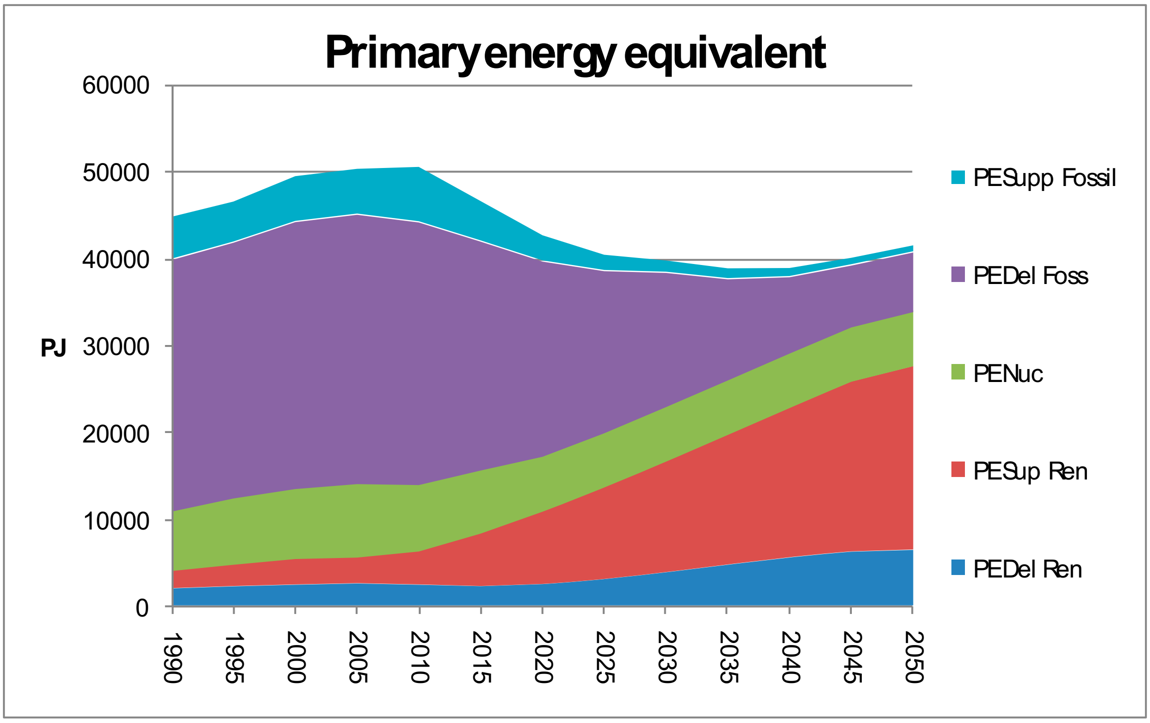


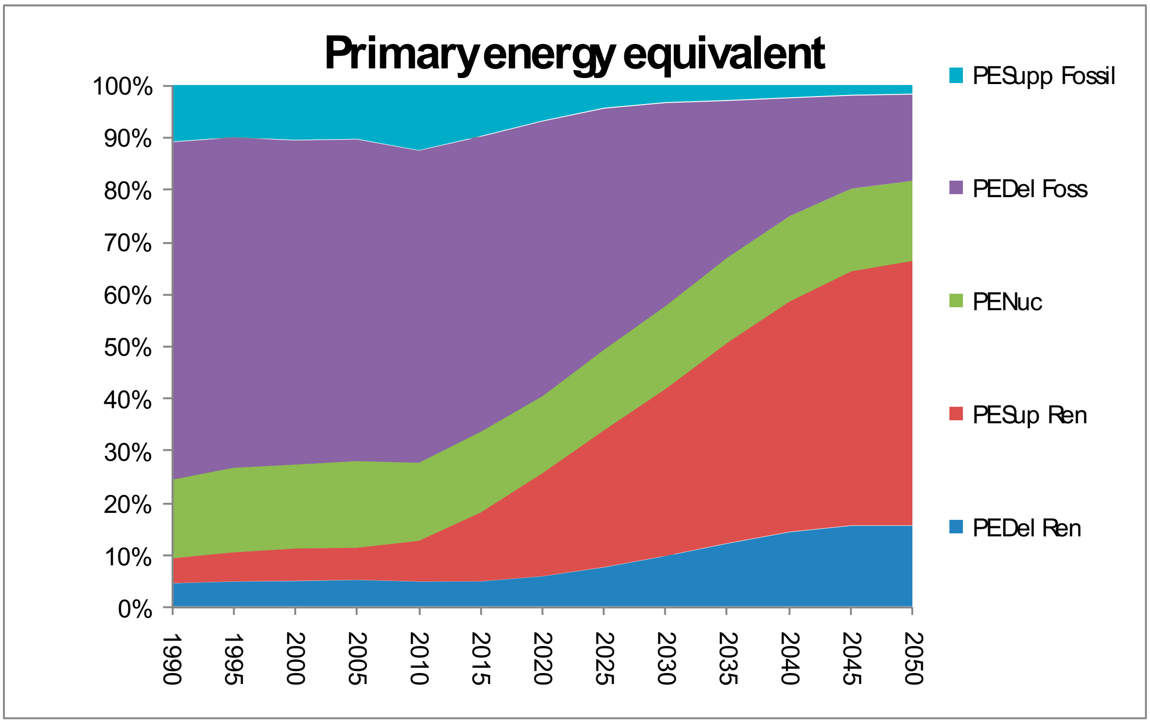


Primary energy renewable fraction increases from 9% in 1990 to 26% in 2020. Official sources put the current fraction at 6-7%, so the accounting conventions used here give a larger fraction.

LEGEND KEY	
PE Del Ren	Delivered renewable
PE Sup Ren	Supply renewable
PE Nuc	Nuclear
PE Del Foss	Delivered fossil
PE Supp Fossil	Supply fossil

Figure 64 EU30pc20N scenario ; primary energy equivalent





The results for the EU30pc20N scenario show:

- The delivered renewable fraction is much smaller than for total primary energy fraction, because of accounting convention;
- Renewable energy as a fraction of total primary energy equivalent increases from 9% to 26% by 2020, approximately a threefold increase;
- The main increase in this scenario is due to renewable electricity generation;

These energy flows are included in the SEEScen model, but are currently omitted from the renewable energy fraction and the fraction will be underestimated :

- Ambient heat from heat pumps. This will become increasingly significant as fossil gas is replaced by electric heat pumps.
- Passive solar gains. These are difficult to calculate accurately, and should gross or net gains through windows be reported?

CONCLUSIONS

The main conclusions are:

- Renewable energy statistics for some sources absent or poor.
- The conventions for renewable energy accounting are arbitrary.
- The conventions adopted here give a renewable contribution about 50% higher than some ‘official’ EU figures
- Whatever the conventions, the renewable fraction can be increased by reducing energy demand with energy efficiency. This underlines the importance of a coherent, comprehensive energy policy.
- The EU30pc20N scenario has about 26% renewable energy contribution in 2020, as compared to a current fraction of about 9%.

- The current ‘official’ conventions give a current fraction of about 6-7%, and so this would probably rise to about 20% in 2020 in the EU30pc20N scenario
- A thorough assessment of renewable fraction conventions and calculations is required; this is especially since the conventions will affect countries very differently, and hence make them critical to any burden sharing negotiations.

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Low Emission Energy Scenarios for the European Union

REPORT 5785

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Energy consumption is a major cause of carbon dioxide emission, and also largely determines the uncontrolled emissions of many other pollutants. In consequence, energy scenarios are key inputs to the projection of pollution emission, and the formulation of strategies to reduce pollution and achieve environmental objectives.

Alternative energy strategies including behavioral change, demand management, energy efficiency, and low carbon fuels are explored in this report. In addition to abating greenhouse gas emissions, these strategies can facilitate cheaper and greater abatement of other atmospheric pollutants as compared to higher carbon scenarios.

Naturvårdsverket SE-106 48 Stockholm. Besöksadress: Valhallavägen 195. Tel: +46 8-698 10 00, fax: +46 8-20 29 25, e-post: natur@naturvardsverket.se Internet: www.naturvardsverket.se **Beställningar** Ordertel: +46 8-505 933 40, orderfax: +46 8-505 933 99, e-post: natur@cm.se Postadress: CM-Gruppen AB, Box 110 93, 161 11 Bromma. Internet: www.naturvardsverket.se/bokhandeln